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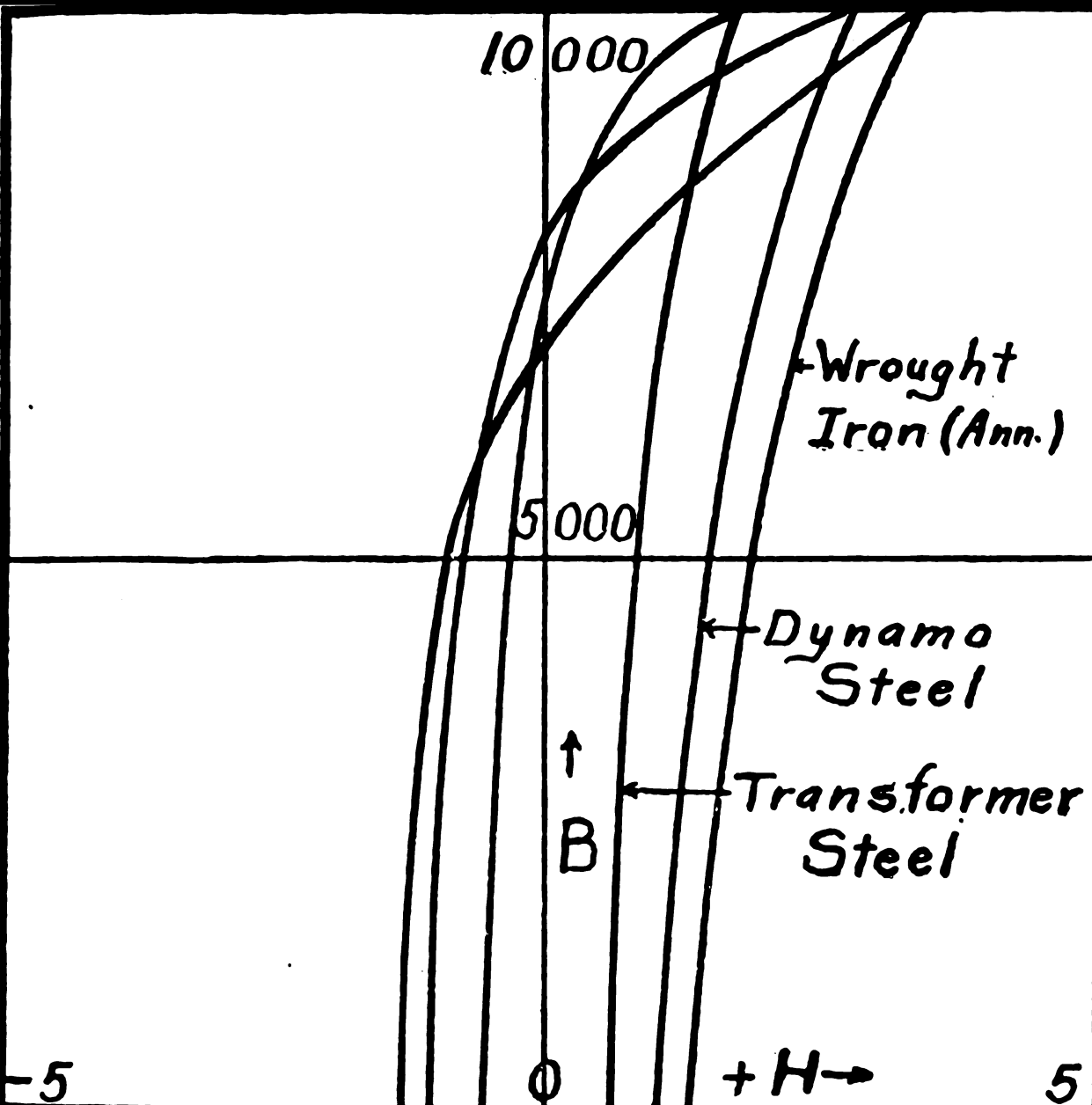
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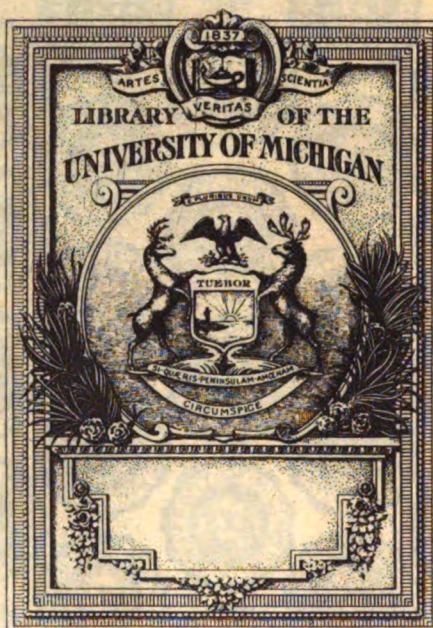
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CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 17

MAGNETIC TESTING

[2d Edition]

Issued December 1, 1910



WASHINGTON
GOVERNMENT PRINTING OFFICE

1910

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MAGNETIC TESTING

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1. SCOPE OF THE MAGNETIC TESTING

Permeability and hysteresis tests are made by the ballistic method on magnetic materials in the form of round or rectangular bars and sheets. For these tests two specimens of each sample, at least 25 cm, and preferably 35 cm in length, should be furnished. The permissible cross section is determined by the dimensions of the holes of the coils and yokes used. The apparatus on hand at present will receive round rods of the following diameters:

0.95 cm ($\frac{3}{8}$ inch).
1.00 cm
1.27 cm ($\frac{1}{2}$ inch).

Rectangular bars may be of any section which will pass through a hole 1.27 cm in diameter. Sheet metal 5 cm wide, or under, and of the same length as for rods, may be used.

For these measurements two rods or strips of the material to be tested have their ends joined by two soft iron yokes so as to form the four sides of a rectangle. Each bar is surrounded by a magnetizing and a test coil. The change in the magnetic flux embraced by the test coil when the magnetizing current is altered is measured ballistically. Further details are given below.

Tests of nonmagnetic materials, such as are used for chronometers and other instruments, and feebly magnetic materials and investigations on magnetic properties at high and low temperatures can also be made. Bismuth spirals, for measurement of magnetic fields, will be calibrated.

The Bureau is prepared to calibrate permeameters and other apparatus used in magnetic measurements and to make investigations on the magnetic properties of materials.

A limited number of bars of carefully aged iron and steel have been prepared and will be supplied to testing laboratories and manufacturers as standards, at little more than the amount of the fee for testing.

Wattmeter tests for energy losses due to alternating magnetization are carried out upon sheet iron and steel, such as is used in the cores of transformers. A special apparatus designed for this purpose is described below. This serves to determine the losses due to hysteresis and eddy currents. A curve showing the relation between the flux density in the test specimen and the wattless component of magnetizing current can also be furnished when desired. Tests to determine the aging quality of this material are also carried on. Not less than 5 pounds (2.5 kg) should be submitted. The losses are measured at 60 cycles and 10 000 gauss, unless otherwise specified, and the results are accurate within 2 per cent.

Transformers are tested for core loss under normal working conditions; and by the measurement of resistances and impedance in addition the efficiencies and regulation can be computed. For tests of instrument transformers, including measurements of ratio, phase angles, regulation, etc., see Bureau Circular No. 20.

2. DESCRIPTION OF WORK

(a) GENERAL

The induction which a bar of iron or steel will assume under a given magnetizing force depends upon the previous magnetic condition of the specimen, and upon the rate of change from one magnetic state to another. It is modified by the presence of mechanical vibration and depends to some extent on temperature. It is therefore desirable to state the conditions under which the test is made.

All the ordinary tests on magnetic material except aging are made at a constant temperature of 25° C. This is in view of the fact that all the magnetic quantities, including the normal induction, the hysteresis loop, and the losses due to hysteresis and eddy currents, depend upon the temperature of the specimen. The relation is not a simple one, and is not the same for all materials. In view of these facts, it seems desirable to make all such measurements at a fixed temperature.

It is important that there be no mechanical vibration of the specimen during the test. Such vibrations tend to give an induction greater than normal for increasing magnetizing forces, and too small values for decreasing forces. Hence, the test specimen is always protected from mechanical vibrations in ballistic measurements.

The results found for rolled sheets usually depend upon whether the material is magnetized parallel to the direction of rolling or at right angles to this direction. When not otherwise specified and the dimensions of sheets

submitted permit it, the test pieces will be so cut that the flux traverses half of them parallel to the direction of rolling, and half normal thereto.

The measurement of flux density requires a knowledge of the cross-sectional area of the specimen. For rods and bars the cross section is determined from the dimensions. In sheet metal, however, it is not determined by direct measurement, but from values of mass, length, and density. The density of each specimen is experimentally determined, as experience shows that the assumption of any specified value introduces an uncertainty in the result which is greater than the inaccuracy of the magnetic measurements.

(b) **NORMAL INDUCTION AND HYSTERESIS LOOP**

i). **Normal Induction.**—If a bar of thoroughly demagnetized iron is subjected to a magnetizing force, it experiences a certain induction. This induction will be greater if the magnetizing force is applied suddenly than for a slower growth of magnetizing current. If the magnetizing force is repeatedly applied and removed, the values of the induction obtained differ somewhat. If the magnetizing force is reversed, a change of induction approximately twice the preceding values is obtained. For the first few reversals the change of induction is not constant, but becomes so after a large number of reversals. One-half this constant value of the change in induction on reversal of the magnetizing force is the normal induction, and the locus of such points is the curve of normal induction.

The magnetic properties of a piece of iron or steel may be considered as defined by the curves of normal induction and hysteresis. Before determining the normal induction data, it is necessary that the specimen be freed from its previous magnetization. This is accomplished by subjecting it to a cyclic magnetizing force of one period per second, which is gradually reduced from an initial value, which carries the induction well beyond the point of maximum permeability to a final value somewhat lower than the lowest induction to be studied.

After thorough demagnetization, the lowest magnetizing force to be used is applied and reversed many times, until the iron is brought to a cyclic magnetic state. The induction is then measured and the next higher value of the magnetizing force applied in the same manner. This process is repeated until the required number of points is determined. This is a somewhat laborious operation, but has been found necessary in order to obtain reliable results.

ii). **Hysteresis Loop.**—Before determining the hysteresis loop, the iron is demagnetized as above, and the magnetizing force is applied and increased until the iron is brought up to the maximum induction for which the loop is required. This magnetizing force is repeatedly reversed until the iron is in a normal condition. The magnetizing force is now reduced from its maximum value to a lower one, and the change in magnetic induction corresponding to the change in force is noted. After determining this pair of values, the maximum magnetizing force is again applied and the iron once more brought back to a normal magnetic condition. It is not

necessary, however, to repeat the process of demagnetization. Another point is then determined in the same manner as the first. Points corresponding to negative values of the magnetizing force are obtained by simultaneously reversing and reducing the magnetizing force. Before each determination of a point on the loop the iron is brought back to its normal condition.

This method of measuring the magnetic constants differs somewhat from the old "step by step" method which is still employed in many of the modern commercial permeameters. It has the advantage of making the measurement under more nearly the same conditions that occur in commercial practice, and is practically free from the effects of magnetic viscosity. Further, it is possible to get more consistent results by this method than by the older one, as the effects of imperfect initial demagnetization are not so serious. The numerical data obtained by these two methods are not identical, and in publishing results of work of the highest precision it is desirable to specify the method of measurement.

iii). **Selection of Test Points.**—In defining the magnetic properties of a bar of iron or steel, it is neither necessary nor practicable to give complete normal and hysteresis data for all values of the magnetizing force. Certain data may be chosen as characteristic and the magnetic properties inferred from these.

The upper limit of the magnetizing force to be applied is determined by the heating of the magnetizing coil. The magnetic constants for high values of the magnetizing force change slowly and quite regularly, and for a considerable range may be obtained by extrapolation from the data of lower magnetizations. However, magnetizing forces up to 300 gaussses can be employed. This upper limit of 300 has reference to the magnetizing force employed in the determination of normal induction data. It is not desirable to carry the cyclic induction measurements through such a wide range. A single hysteresis loop having a maximum induction of 10 000 gaussses gives a close index to the hysteretic properties at all inductions. In some cases it might be desirable to supplement these data by the residual induction and coercive force at other values of the maximum induction.

It is, of course, desirable that the number of observations be as small as possible and yet yield the required continuity of data. For most purposes the magnetizing forces required to produce inductions of 5000, 10 000, 15 000, and 20 000 would indicate clearly enough the shape of the normal induction curve. If one is interested in some particular range, measurements in this region could be taken closer together—for instance, every 1000 gaussses—or the measurements may be confined to one particular region. A single pair of data may be sufficient for some purposes.

In the hysteresis data, likewise, the labor of measurement is reduced to a minimum by drawing the curve from the three principal points, namely, the tip of the magnetic cycle, the residual induction remaining when the magnetizing force is removed, and the coercive force or the magnetizing force required to reduce the induction to zero.

Such a determination of four points on the normal induction curve and three points on the hysteresis curve gives a fair idea of the magnetic properties of a sample of iron. If several specimens are thus examined at corresponding points, it is possible to make comparisons of the different specimens and classify them into different grades without drawing complete induction curves as would be necessary if the different specimens are tested at irregular points.

iv). **Standard Specimens.**—If a bar is to be used as a standard of comparison, or for the purpose of calibrating a permeameter, it is necessary to determine a considerable number of points of the curve in the region where the apparatus is to be used. Such measurements should be taken with greater care than those on a specimen typical of a large lot which individually may differ considerably from the mean.

In measurements of the highest precision, the magnetic circuit consists of two rods joined at their ends by two soft iron yokes. The magnetomotive force is applied by means of two solenoids and a set of compensating coils. The magnetizing current in each solenoid is capable of independent adjustment until the fluxes in the two rods are equal. The compensating coils are distributed over the four joints of the magnetic circuit and the current is adjusted so that there is no magnetic leakage between the middle and ends of the test specimens. When the magnetic flux has thus been rendered uniform throughout the circuit the true magnetic force and induction may be determined by the ballistic method.¹

v). **Form of Specimen.**—The labor of a test is reduced and the precision increased by having a certain degree of uniformity in the test specimens. The minimum length of test piece in the ballistic tests is 25 cm (10 inches). A length of 35 cm (14 inches), however, is preferred, as more precise measurements can be made on the longer specimen. Round rods may be 1 cm or 1.27 cm ($\frac{1}{2}$ inch) or 0.95 cm ($\frac{3}{8}$ inch) in diameter. Specimens of any uniform section which have one pair of parallel sides and will pass through a round hole 1.27 cm ($\frac{1}{2}$ inch) in diameter may be submitted.

Two rods of the same material should be submitted for each test. For single rods and for specimens of other dimensions than those indicated a special fee is charged.

For sheet metal the test material consists of four strips 5 cm (2 inches) wide, two cut parallel and two perpendicular to the direction of rolling. The material submitted should be chosen from different parts of the sheet and of sufficient size to permit the final cutting to size being done at this laboratory. For this purpose four strips 7.5 by 40 cm (3 by 16 inches) are satisfactory. Crayon lines should be drawn on each specimen parallel to the direction of rolling.

¹A fuller account of the arrangement of the magnetic and electric circuits, of the manner of securing uniformity of flux, and of other details of the ballistic method employed is found in Technical Paper No. 117, reprinted from the Bulletin of the Bureau of Standards, Vol. 6, No. 1.

(c) HYSTERESIS AND EDDY CURRENT LOSSES

The total losses due to the combined effects of hysteresis and eddy currents in sheet iron and steel when subjected to a sine wave of alternating magnetic flux are measured by the method described in full in Technical Paper No. 109 (from Bulletin of this Bureau, vol. 5, pp. 453-482). This paper will be mailed on request. For this test ten small sheets approximately 30 cm (12 inches) square are required. These are cut at this Bureau into strips 5 by 25.4 cm and made up into four bundles, which form the four sides of a square magnetic circuit. The arrangement is similar to that proposed by Epstein, but differs from it in having good magnetic joints at the corners of the square. It is thus possible to secure an accuracy of 1 or 2 per cent with a smaller quantity of material, and yet without appreciable distortion of the wave form. In the paper cited above it is shown that the sheet material in common use varies very widely in quality, and the quality is not closely related to the cost. Some of the results are given in Tables I and II.

TABLE I

Hysteresis and Eddy Current Losses

Ordinary steel

Designation	Thickness	ERGS PER GRAM PER CYCLE								WATTS PER POUND AT 60 CYCLES AND 10 000 GAUSSSES		
		10 000 gaussses				5000 gaussses						
	cm	60~	30~	Hysteresis	Eddy currents	60~	30~	Hysteresis	Eddy currents	Eddy currents for gage 29*	Hysteresis	Total
E.....	0.0476	971	853	735	236	304	275	246	58	0.36	2.00	2.36
F.....	0.0280	766	716	666	100	247	233.5	220	27	0.44	1.81	2.25
G.....	0.0394	773	668	563	210	247	220	193	54	0.47	1.53	2.00
H.....	0.0307	558	485	412	146	177.5	158	138.5	39	0.54	1.12	1.66
J.....	0.0318	543	442	341	202	166.5	139	111.5	55	0.70	0.93	1.63
K.....	0.0282	518	456	394	124	162	146	130	32	0.54	1.07	1.61
L.....	0.0346	565	473	381	184	175	150	125	50	0.535	1.035	1.57
B ₁	0.0338	554	454	354	200	173	144.5	116	57	0.61	0.96	1.57
M.....	0.0335	550	461	372	178	173	150	127	46	0.55	1.01	1.56
N.....	0.0340	531	426	321	210	161	133	105	56	0.63	0.87	1.50
P.....	0.0437	518	426	334	184	157	132	107	50	0.335	0.91	1.24

* In order to make a fair comparison of quality, the eddy current loss has been computed in each case for a thickness of 0.0357 cm (U. S. standard gage No. 29) on the assumption that the eddy current loss is proportional to the square of the thickness.

TABLE II
Hysteresis and Eddy Current Losses
Silicon steel

Designation.	Thickness cm	ERGS PER GRAM PER CYCLE								WATTS PER POUND AT 60 CYCLES AND 10 000 GAUSSES		
		10 000 gaussses				5000 gaussses				Eddy currents for gage 29*	Hysteresis	Total
		60~	30~	Hysteresis	Eddy currents	60~	30~	Hysteresis	Eddy currents			
Q.....	0.0361	357	330	303	54	113	105.5	98	15	0.14	0.82	0.96
R.....	0.0315	330	309	288	42	104	98.5	93	11	0.15	0.78	0.93
S.....	0.0452	350	314	278	72	108	99	90	18	0.12	0.76	0.88
T.....	0.0338	310	280	250	60	96	87	78	18	0.18	0.68	0.86
U.....	0.0346	312	291	270	42	98	92	86	12	0.12	0.74	0.86
V.....	0.0310	298	275	251	47	92	85.5	79	13	0.17	0.68	0.85
W.....	0.0305	240	218	197	43	74.7	68.5	62.3	12.4	0.16	0.54	0.70
X.....	0.0430	265	232	200	65	80.8	72.5	64.2	16.6	0.12	0.54	0.66

* In order to make a fair comparison of quality, the eddy current loss has been computed in each case for a thickness of 0.0357 cm. (U. S. standard gage No. 29) on the assumption that the eddy current loss is proportional to the square of the thickness.

It is seen that ordinary steel varies from 1.24 to 2.36 watts per pound for United States standard gage No. 29 (thickness 0.0357 cm) at a frequency of 60 cycles per second and a magnetic induction of 10 000 gaussses. Silicon steel varies from 0.66 to 1 watt per pound under the same conditions. These figures correspond to 460 and 865 ergs per cycle per gram for ordinary steel and 246 to 368 ergs per cycle per gram for silicon steel. In addition to this variation in the original quality of the material there is a great difference in its constancy with time. Some material shows very decided aging, which in one case amounted to as much as 67 per cent in 500 hours. Other specimens, including most silicon steels, show little or no alteration with use.

The great saving in cost of power due to improvement in core material is generally recognized, but the following example gives a practical illustration.

The benefits derived from the use of high grade material are usually divided between copper and iron losses by judicious designing, but to simplify matters let us assume that the design is fixed for a 5-kilowatt transformer, and using the material R in table above the loss is 45 watts. If the material X be substituted, the core loss is reduced to 32.2 watts. In operation for 8760 hours, or one year, the saving of 12.8 watts amounts to 112 kilowatt-hours. At a cost of 1 cent per kilowatt-hour this amounts to \$1.12, which at 10 per cent (allowing for depreciation as well as interest) represents a capital of \$11.20. *In other words the buyer could, with advantage, pay any amount up to \$11 more for the sake of getting the better material in his core, and the manufacturer could pay 28 cents per pound more for the 40 pounds of core material used.*

If the better silicon steel were to cost 2.8 cents per pound more than the other (which is improbable), the difference in cost of the steel would be \$1.12, and the user would each year save 100 per cent of the extra cost.

The comparison between the poorer silicon steel and the ordinary steel is even more marked. The core loss for material *N* would be 73 watts, a difference of 28 watts from *R*. In a year this would amount to 245 kilowatt-hours, costing \$2.45, thus practically reducing the value of the transformer by \$24.50. Yet the difference in cost of material is only \$1.70, if we take the price of silicon steel delivered at the factory to be 7½ cents per pound and that of ordinary steel to be 3¼ cents per pound, and assume 40 pounds to be necessary.

Any frequency from 25 cycles to 90 cycles per second can be used for the test. When it is desired to determine the eddy current and hysteresis losses separately, tests at two frequencies (such as 30 and 60 cycles) are made, from the results of which the two components of the loss can be approximately calculated.

Any flux densities between 1000 and 14 000 gaussses may be specified. The flux density stated for any measurement is the average value for all the material. The deviations from this value in different parts of the steel are small. The maximum flux Φ is computed from the effective voltage E

induced in a secondary winding from the relation $\Phi = \frac{10^8 E}{4.44 N n}$ where

n = frequency.

N = number of turns in secondary winding.

When so desired, an ammeter is included in the magnetizing circuit, its reading giving the effective value of the current in the magnetizing coil. With the aid of the wattmeter and voltmeter readings the wattless component of the equivalent sine wave can be computed. A curve giving the relation between this quantity and the magnetic induction is for most purposes more valuable than a curve showing the permeability, since this curve indicates the *effective* value of the current necessary to magnetize, while the permeability indicates the *maximum* current necessary to magnetize, to a given value of magnetic induction.

Aging tests are carried on by heating the material in an oven, the usual period being two weeks and the temperature between 90° and 100° C. Other periods and temperatures can be used when desired. Measurements of energy loss are made at the beginning and end of this heating, and are made at two frequencies, in order to determine whether the change is merely in the hysteresis or also in the electrical conductivity of the material. The flux density used should have the value which will be applied to the material in practice, since the hysteresis changes differently for different values of flux density, the change usually being greater in the region of maximum permeability than for the higher flux densities now common in power transformers.

3. TECHNICAL PAPERS ON MAGNETIC WORK.

The following papers upon magnetic subjects have been published by the Bureau. They are issued in pamphlet form and will be sent upon request. They may be designated by the numbers which precede the titles in the list. A complete list of the technical publications of the Bureau, with brief abstracts of contents, will also be sent upon application.

No. 38. Experiments on Heusler Magnetic Alloys. K. E. Guthe and L. W. Austin.

No. 78. On the Best Method of Demagnetizing Iron in Magnetic Testing. C. W. Burrows.

No. 87. Apparatus for the Determination of the Form of a Wave of Magnetic Flux. M. G. Lloyd and J. V. S. Fisher.

No. 88. Effect of Wave Form upon the Iron Losses in Transformers. M. G. Lloyd.

No. 106. Dependence of Hysteresis upon Wave Form. M. G. Lloyd.

No. 108. Errors in Magnetic Testing with Ring Specimens. M. G. Lloyd.

No. 109. The Testing of Transformer Steel. M. G. Lloyd and J. V. S. Fisher.

No. 117. The Determination of the Magnetic Induction in Straight Bars. C. W. Burrows.

4. REGULATIONS

(a) **Application for Test.**—The request for test of an instrument or specimen should state explicitly the points at which test is to be made and the temperature or any other conditions which it is desired should be observed. Whenever possible, the request should be accompanied by the fee as shown in the appended schedules.

(b) **Identification Marks.**—Instruments or specimens and the packages in which they are shipped should both be plainly marked to facilitate identification, preferably with the name of the shipper, and a special reference number given to the article and mentioned in the letter requesting the test.

(c) **Shipping Directions.**—Instruments should be securely packed in cases or packages which may be used in returning them to the owner. Tops of cases should be screwed down whenever possible. Transportation charges are payable by the party desiring the test, and should be prepaid. Instruments and standard bars will be returned by express "collect," but specimens of material will not be returned unless requested.

(d) **Address.**—Articles should be addressed simply, "Bureau of Standards, Washington, D. C." Delays incident to other forms of address will thus be avoided. Articles delivered in person or by messenger should be left at the office of the Bureau and should be accompanied by a written statement of the test desired.

(e) **Remittances.**—Fees may be sent by money order or check drawn to the order of the "Bureau of Standards." Delays in forwarding fees will involve corresponding delays in the completion of tests, as certificates are not issued, nor articles returned, until all fees due thereon have been received.

5. SCHEDULES OF FEES

EFFECTIVE JANUARY 1, 1910

Schedules 90 and 91 are for tests made on specimens of the form indicated in paragraph 2 (b) v.

Schedule 90.—*Short ballistic test*

Including normal data of one of the two specimens supplied for the following inductions: 5000, 10 000, 15 000, 20 000, or any four values produced by forces under 300 gaussess; and hysteresis data for a maximum induction of 10 000 gaussess, giving the residual induction under no magnetizing force, and the coercive force, or force necessary to reduce the induction to zero.

(a) Normal induction and permeability	\$3.00
(b) Hysteresis data	3.00
(c) Normal and hysteresis data	5.00
(d) Curve (extra)	.50

If both specimens are to be tested the fee for the second is one-half the above schedule.

Schedule 91.—*Complete ballistic test.*

Including normal data of one of the two specimens supplied, for every 2000 gaussess up to 20 000, produced by forces under 300 gaussess; and hysteresis data for a maximum induction of 10 000 gaussess, including the following ten points of the loop: 0, ± 2000 , ± 4000 , ± 6000 , ± 8000 , and 10 000.

(a) Normal induction and permeability	\$6.00
(b) Hysteresis data	6.00
(c) Normal and hysteresis data	10.00
(d) Curve (extra)	.75

Special tests not enumerated above will be charged at reasonable rates.

If both specimens are to be tested, the fee for the second is one-half the above schedule.

Schedule 92.—*Standard bars*

These bars, of lengths 25, 30, and 35 cm, are carefully aged and supplied with a certificate containing the data of the precision test of schedule 91.

Material.	Diameter of section.
Annealed wrought iron (round).....	0.95 cm ($\frac{3}{8}$ inch)
Annealed wrought iron (round).....	1.00 cm
Annealed wrought iron (round).....	1.27 cm ($\frac{1}{2}$ inch)
Low carbon steel (round).....	0.95 cm ($\frac{3}{8}$ inch)
Low carbon steel (round).....	1.00 cm
Low carbon steel (round).....	1.27 cm ($\frac{1}{2}$ inch)

ONE BAR

(a) Normal data.....	\$7. 00
(b) Hysteresis data.....	7. 00
(c) Normal and hysteresis data.....	11. 00
(d) Standard bars without certificate.....	2. 00

TWO BARS

(k) Normal data.....	\$11. 00
(i) Hysteresis data.....	11. 00
(j) Normal and hysteresis data.....	17. 00

Schedule 93.—*Wattmeter measurements*

(a) For test of energy loss at one frequency and one flux density.....	\$4. 00
(b) For each additional flux density.....	. 50
(c) For each additional frequency.....	1. 00
(d) For values of wattless component of magnetizing current (extra).....	1. 00
(e) When not otherwise specified, test will be made at 30 cycles and 60 cycles for a flux density of 10 000 gaussses, fee.....	5. 00
(h) Aging test, two weeks at 90–100° C, with repetition of test (a).....	8. 00
Special tests not mentioned above will be charged at reasonable rates.	

Schedule 94.—*Miscellaneous.*

(a) For tests not enumerated above reasonable fees will be charged.

The Bureau will cooperate with manufacturers, scientists, and others interested in the subjects of methods of measurement, measuring instruments, and physical constants, and will place at the disposal of those interested such information relative to these subjects as may be in its possession.

The Bureau will also aid in the solution of problems arising in technical or scientific work, within its scope, and to this end correspondence is invited. Persons interested in magnetic problems and magnetic measuring instruments and methods are welcome to visit the laboratories of the Bureau, where many of the leading types of apparatus may be seen. Communications should be addressed simply "Bureau of Standards, Washington, D. C."

S. W. STRATTON,
Director.

Approved:

BENJ. S. CABLE,
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S. W. STRATTON, DIRECTOR

No. 17

MAGNETIC TESTING

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MAGNETIC TESTING

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I. SCOPE OF CIRCULAR

This circular deals with the fundamental magnetic quantities, with empirical formulas giving the relations between these quantities, with typical data of magnetic materials, and with the methods of magnetic measurements employed at the Bureau of Standards.

An effort has been made to include in the circular as much as possible of the general information regarding magnetic subjects which the Bureau from time to time has been called upon to furnish.

II. MAGNETIC QUANTITIES**1. INDUCTION**

The induction B in a bar of iron or steel is defined in terms of the quantity of electricity which flows through a test coil closely encircling the specimen when the magnetization in the bar is removed, by the formula

$$B = \frac{QR}{AN} 10^8$$

where Q = total quantity of electricity in coulombs.

R = resistance in ohms.

A = cross section of specimen in square centimeters.

N = number of turns in test coil.

The unit of induction is called the gauss.

The induction may also be defined in terms of the emf induced in a coil when the flux encircled by the coil is changing, by the formula

$$e = AN \frac{dB}{dt}$$

when e is the emf induced in the coil by the changing flux.

If the induction varies according to the sine law, this equation reduces to

$$E = 4.44 BANn \times 10^{-8}$$

where E is the effective emf and n is the frequency. This latter formula is the one commonly used in transformer design.

The induction which a bar of iron or steel will assume under a given magnetizing force depends upon the previous magnetic condition of the specimen and upon the rate of change from one

magnetic state to another. It is modified by the presence of mechanical vibration and depends to some extent on temperature. It is therefore desirable to state the conditions under which the test is made.

All the ordinary tests on magnetic material except aging are made at a constant temperature of 25° C. This is in view of the fact that all the magnetic quantities, including the normal induction, the hysteresis loop, and the losses due to hysteresis and eddy currents, depend upon the temperature of the specimen. The relation is not a simple one and is not the same for all materials. In view of these facts it seems desirable to make all such measurements at a fixed temperature.

It is important that there be no mechanical vibration of the specimen during the test. Such vibrations tend to give an induction greater than normal for increasing magnetizing forces, and too small values for decreasing forces. Hence, the test specimen is always protected from mechanical vibrations in ballistic measurements.

The results found for rolled sheets usually depend upon whether the material is magnetized parallel to the direction of rolling or at right angles to this direction. When not otherwise specified and the dimensions of sheets submitted permit it, the test pieces will be so cut that the flux traverses half of them parallel to the direction of rolling, and half normal thereto.

The measurement of flux density requires a knowledge of the cross-sectional area of the specimen. For rods and bars the cross section is determined from the dimensions. In sheet metal, however, it is not determined by direct measurement, but from values of mass, length, and density. The density of each specimen is experimentally determined, as experience shows that the assumption of any specified value introduces an uncertainty in the result which is greater than the inaccuracy of the magnetic measurements.

NORMAL INDUCTION.—If a bar of thoroughly demagnetized iron is subjected to a magnetizing force, it experiences a certain induction. This induction will be greater if the magnetizing force is applied suddenly than for a slower growth of magnetizing current. If the magnetizing force is repeatedly applied and removed, the values of the induction obtained differ somewhat.

If the magnetizing force is reversed, a change of induction approximately twice the preceding values is obtained. For the first few reversals the change of induction is not constant, but becomes so after a large number of reversals. One-half this constant value of the change in induction on reversal of the magnetizing force is the normal induction, and the locus of such points is the curve of normal induction.

The magnetic properties of a piece of iron or steel may be considered as defined by the curves of normal induction and hysteresis. Before determining the normal induction data, it is necessary that the specimen be freed from its previous magnetization. This is accomplished by subjecting it to a cyclic magnetizing force of one period per second, which is gradually reduced from an initial value, which carries the induction well beyond the point of maximum permeability to a final value somewhat lower than the lowest induction to be studied.

After thorough demagnetization, the lowest magnetizing force to be used is applied and reversed many times, until the iron is brought to a cyclic magnetic state. The induction is then measured and the next higher value of the magnetizing force applied in the same manner. This process is repeated until the required number of points is determined. This is a somewhat laborious operation, but has been found necessary in order to obtain reliable results.

HYSTERESIS LOOP.—Before determining the hysteresis loop, the iron is demagnetized as above, and the magnetizing force is applied and increased until the iron is brought up to the maximum induction for which the loop is required. This magnetizing force is repeatedly reversed until the iron is in a normal condition. The magnetizing force is now reduced from its maximum value to a lower one, and the change in magnetic induction corresponding to the change in force is noted. After determining this pair of values, the maximum magnetizing force is again applied and the iron once more brought back to a normal magnetic condition. It is not necessary, however, to repeat the process of demagnetization. Another point is then determined in the same manner as the first. Points corresponding to negative values of the magnetizing force are obtained by simultaneously reversing and reducing

the magnetizing force. Before each determination of a point on the loop the iron is brought back to its normal condition.

This method of measuring the magnetic constants differs somewhat from the old "step by step" method, which is still employed in many of the modern commercial permeameters. It has the advantage of making the measurement under more nearly the same conditions that occur in commercial practice, and is prac-

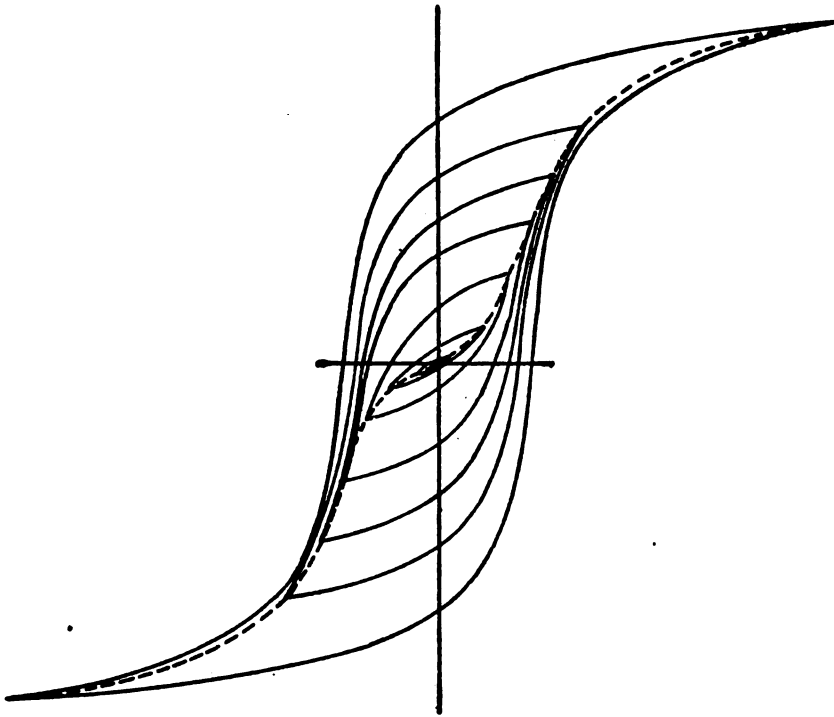


FIG. 1.—Showing that the curve of normal induction is the locus of the tips of the hysteresis loops

tically free from the effects of magnetic viscosity. Further, it is possible to get more consistent results by this method than by the older one, as the effects of imperfect initial demagnetization are not so serious. The numerical data obtained by these two methods are not identical, and in publishing results of work of the highest precision it is desirable to specify the method of measurement.

The relation between the hysteresis loop and the curve of normal induction is shown by Figure 1.

The locus of the tips of the hysteresis loops is the curve of normal induction.

SELECTION OF TEST POINTS.—In defining the magnetic properties of a bar of iron or steel, it is neither necessary nor practicable to give complete normal and hysteresis data for all values of the magnetizing force. Certain data may be chosen as characteristic and the magnetic properties inferred from these

The upper limit of the magnetizing force to be applied is determined by the heating of the magnetizing coil. The magnetic constants for high values of the magnetizing force change slowly and quite regularly, and for a considerable range may be obtained by extrapolation from the data of lower magnetizations. However, magnetizing forces up to 300 gaussses can be employed in the usual testing apparatus without undue heating of the coils. This upper limit of 300 has reference to the magnetizing force employed in the determination of normal induction data. It is not desirable to carry the cyclic induction measurements through such a wide range. A single hysteresis loop having a maximum induction of 10 000 gaussses gives a close index to the hysteretic properties at all inductions. In some cases it might be desirable to supplement these data by the residual induction and coercive force at other values of the maximum induction.

It is, of course, desirable that the number of observations be as small as possible and yet yield the required continuity of data. For most purposes the magnetizing forces required to produce inductions of 5000, 10 000, 15 000, and 20 000 indicate clearly enough the shape of the normal induction curve. If one is interested in some particular range, measurements in this region could be taken closer together—for instance, every 1000 gaussses—or the measurements may be confined to one particular region. A single pair of data may be sufficient for some purposes.

In the hysteresis data, likewise, the labor of measurement is reduced to a minimum by drawing the curve from the three principal points, namely, the tip of the magnetic cycle, the residual induction remaining when the magnetizing force is removed, and

the coercive force or the magnetizing force required to reduce the induction to zero.

Such a determination of four points on the normal induction curve and three points on the hysteresis curve gives a fair idea of the magnetic properties of a sample of iron. If several specimens are thus examined at corresponding points, it is possible to make comparisons of the different specimens and classify them into different grades without drawing complete induction curves, as would be necessary if the different specimens are tested at irregular points.

2. MAGNETIZING FORCE

The magnetizing force, or magnetic field intensity, at any point is numerically equal to the mechanical force acting upon a unit magnetic pole at that point. In magnetic testing the magnetizing force is generally produced by means of a solenoid carrying current. At the center of a very long, uniformly wound solenoid of N turns on a length L , carrying current of I amperes, the magnetizing force due to the current in the solenoid in cgs electromagnetic units is

$$H = 0.4 \pi \frac{N}{L} I$$

This is the total magnetizing force only when there are no free magnetic poles in or near the solenoid. The unit is called the gauss or the gilbert per centimeter.

Another unit in use is the ampere-turn per centimeter, which is 1.257 times the gilbert per centimeter. In ampere-turns per centimeter, $H = \frac{N}{L} I$, subject to the same restrictions as the formula above. The names, ampere-turn per centimeter, and to a less degree the gilbert per centimeter are somewhat misleading. It is only in special cases, such as within a uniformly wound and practically infinite solenoid or a uniformly wound toroid, that the "ampere-turns per centimeter" of magnetizing force are equal to the product of the number of amperes by the number of turns per centimeter. In all other cases the magnetizing force in this unit is the product of the number of amperes by the number of turns per centimeter of the infinite solenoid which produces the same magnetic field at its center that exists at the point considered.

3. CORE-LOSS

The core-loss is the power consumed within the iron when it is subjected to an alternating magnetization at a given frequency and induction. The standard core-loss is the total loss in watts per kilogram when the iron is subjected to an alternating magnetization of 60 cycles per second and an induction of 10 000 gauss.

III. SCOPE OF MAGNETIC TESTING

The magnetic testing¹ of the Bureau comprises the determination of the magnetic properties of materials and of permanent magnets, and the calibration of magnetic apparatus.

1. NORMAL INDUCTION AND HYSTERESIS

Normal induction and hysteresis involve the determination of normal induction, permeability, the hysteresis loop, residual induction, and coercive force.

RODS AND CASTINGS.—These should be submitted in the form of bars. Two bars of the same material are required, usually only one of which is to be tested and the second to be used as an auxiliary bar. The minimum length of the test piece is 25 cm (10 inches). Round rods may be 0.6 cm, 0.95 cm (three-eighths inch), 1 cm, or 1.27 cm (one-half inch) in diameter. Bars of any rectangular cross section which will pass through a hole 1 cm by 5 cm may be submitted.

For material to be used for electromagnets, field cores, etc., the usual test rod is 25 cm (10 inches) long and 1.27 cm (one-half inch) in diameter. Magnet steel is usually submitted in sizes as rolled and 25 cm long. Magnet steel may be hardened either by the submitter of the test or by the Bureau.

SHEET METAL.—Sheet metal may be submitted in either of two forms:

1. One form consists of 5 kg of strips 50 cm by 3 cm, half cut parallel and half cut at right angles to the direction of rolling.
2. The second form consists of 10 sheets approximately 30 cm (12 inches) square. These are cut at the Bureau into strips 5 cm by 25.4 cm, half parallel and half at right angles to the direction of rolling. Test material is usually submitted in this form.

¹ A schedule of fees for electric, magnetic, and photometric testing and general instructions to applicants for tests are given in Circular No. 6 of this Bureau.

The same material that is submitted for a core-loss test is also suitable for normal induction and hysteresis determinations.

In addition to the above, normal induction and hysteresis tests may be made on single strips 25 cm (10 inches) by 5 cm (2 inches). For this test, as in the case of rods, two strips of the same material are required. The final cutting to size may be made at the Bureau without extra charge. This single-strip test is intended only for investigations in which it is desired to know the characteristics of an individual strip. Core-loss determinations are not made on the single-strip sample.

STANDARD DATA.—The standard test for steel for electromagnets, etc., is the determination of the magnetizing forces corresponding to inductions of 2000, 4000, 6000, 8000, 10 000, 12 000, 14 000, 16 000, 18 000, and 20 000 gaussses, or such values as may be obtained without exceeding a magnetizing force of 300 gaussses.

The standard test for magnet steel is the determination of the magnetizing force, residual induction, and coercive force corresponding to a maximum induction of 14 000 gaussses.

2. CORE-LOSS

Core-loss tests consist of the determination of the losses due to the alternating magnetization of sheet iron and steel such as are used in transformers and armatures. They may include the separation of the total core-loss into its eddy-current and hysteresis components, and sometimes also the increase in core-loss with time, known as aging.

FORM OF SPECIMEN.—Sheet material intended for core-loss determination may be submitted in either of two forms:

1. One form consists of 10 kg of strips 50 cm by 3 cm, half cut parallel to the direction of rolling and half at right angles to the direction of rolling. These strips should be cut to size by the person submitting the material for test. It may, however, be done at the Bureau. If the cutting is to be done at the Bureau, sufficient material to allow for waste must be supplied.

2. The second form consists of 10 sheets approximately 30 cm (12 inches) square. These are cut at the Bureau into strips 5 cm by 25.4 cm, half parallel and half at right angles to the direction of rolling. Test material is usually submitted in this form.

STANDARD DATA.—The standard core-loss test is the determination of the core-loss at a maximum induction of 10 000 gaussess and a frequency of 60 cycles.

3. SUSCEPTIBILITY

Susceptibility tests involve the determination of the properties of the nonmagnetic materials such as are used in chronometers and other apparatus where magnetic material is objectionable.

4. PERMANENT MAGNETS

The testing of permanent magnets involves the determination of field strength, uniformity of field, constancy of field, and temperature coefficient.

5. MAGNETIC APPARATUS

The constants of the apparatus used in magnetic measurements are frequently incapable of calculation and even though they may be calculated should be checked up experimentally. Experimental calibrations of permeameters, fluxmeters, bismuth spirals, and test coils are made.

IV. MEASUREMENT OF NORMAL INDUCTION AND HYSTERESIS, USING THE BURROWS PERMEAMETER

Standard normal induction and hysteresis data on straight bars are obtained with the Burrows permeameter, which is described below.

1. THE MAGNETIC CIRCUIT

The magnetic circuit for this permeameter consists of two bars and two yokes joined together in the form of a rectangle. The leakage over the middle portion of one of the bars is reduced to zero by proper distribution of the magnetomotive force. With no leakage over the middle portion of the test bar, the magnetizing force may be calculated from the current and the concentration of the magnetizing winding at that point.

Fig. 2 shows the magnetic circuit in detail, together with the method of distributing the magnetomotive force. The bars should be of the same size and material. They are joined at the ends by soft-iron yokes, which make good magnetic joints, and thereby reduce the leakage to a minimum.

The magnetomotive force is applied in three sections—one over the test bar, one over the auxiliary bar, and the third distributed over the four joints. The currents in these three sections are independently adjustable. The test coils indicated by t , a , and j are each of the same number of turns and distributed as shown in the figure; t is wound over the middle of the test bar, a over the middle of the auxiliary bar, and j is wound half over one end and half over the other end of the test bar far enough away from the yokes and joints to avoid any disturbances from these causes.

2. ELECTRICAL CONNECTIONS

Fig. 3 shows diagrammatically the electrical connections both of the magnetizing and test circuits. T , A , and J refer to the

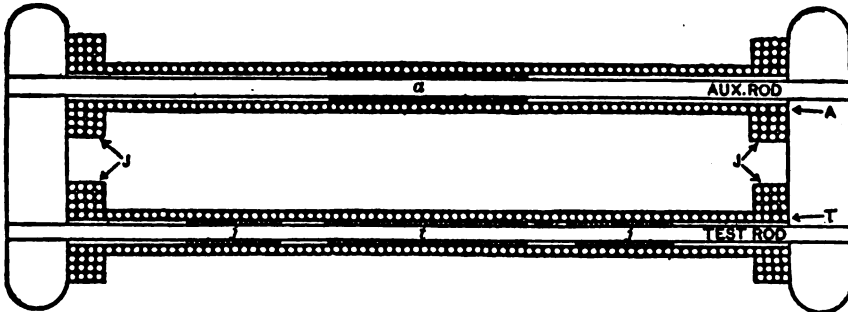


FIG. 2.—Showing the magnetic circuit of the Burrows permeameter and the relative positions of the magnetizing and test coils

magnetizing coils, and M is the primary of a variable mutual inductance; t , a , and j refer to the test coils, and m is the secondary of the mutual inductance. ST , SJ , and SM are reversing switches for the corresponding circuits. ST reverses the current in both T and A . The operation of KT is to connect the resistance $R'T$ around the contact b and then open this contact, thus inserting the resistance $R'T$ without opening the circuit. KJ and K_1A operate in a similar manner. K_1A connects the resistance $R'A$ par. in parallel with RA .

In the secondary or test circuit the dial switch SD connects the galvanometer to the test coil t in opposition to either a , j , or m . With the switch SS thrown to the right the galvanometer is at its maximum sensitivity. With this switch thrown to the left

the resistance RG ser. is placed in series with the test coils and RG par. is placed in parallel with the galvanometer, so that the

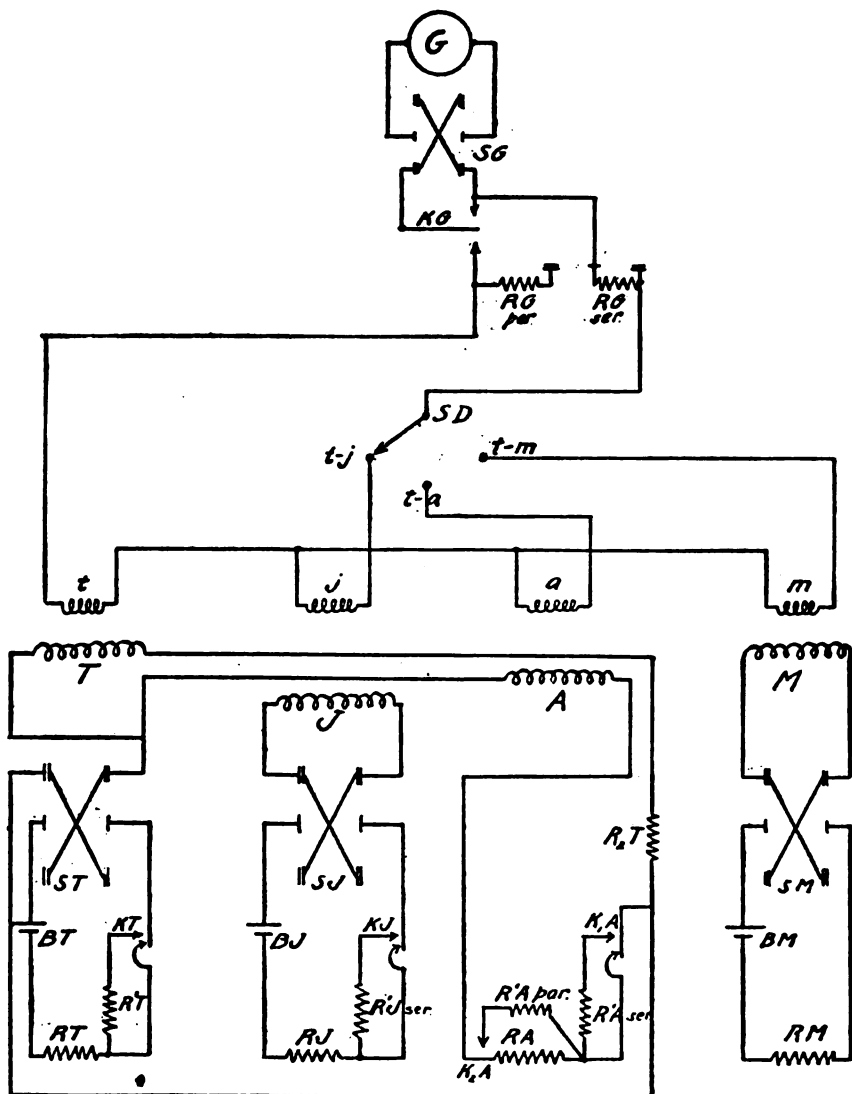


FIG. 3.—Showing electrical connections of the Burrows permeameter

galvanometer can be adjusted to work under critical damping and at a reduced sensitivity.

3. BALLISTIC GALVANOMETER ADJUSTMENT

The galvanometer is calibrated by means of a variable mutual inductance, the secondary of which is always in the galvanometer circuit. This mutual inductance can be set to such a value that the effect on the galvanometer of the reversal of 1 ampere in the primary is the same as the reversal of an induction of 10 000 gaussess through the test coil. Thus, when equal deflections are produced by the reversal of 1 ampere in the primary of the mutual inductance and 10 000 gaussess through the test coil we have the relation

$$B = 10\,000\, I$$

where I is the current in amperes in the primary of the mutual inductance and B is the induction in gaussess in the test bar that will produce the same effect. The value of mutual inductance for this relation is

$$M = AN_s \times 10^{-4}$$

where A is the cross section of the test specimen in square centimeters, N_s is the number of turns in the test coil, and M is the mutual inductance in henries. If the test coil has 100 turns, then

$$M = 0.01\, A$$

When the mutual inductance has been set to the proper value and with switch SS on low sensitivity the resistances RG ser. and RG par. are adjusted so that the galvanometer has approximately critical damping and the deflection is 10 cm upon reversal of 0.1 ampere in the mutual inductance primary; 1 cm deflection then corresponds to $B = 100$.

4. NORMAL INDUCTION

For the determination of normal induction the bars are inserted in the coils and the yokes clamped in place. They are then demagnetized by repeated reversals of a successively decreasing magnetizing current. This demagnetizing current is gradually reduced from a maximum value which brings the magnetization well above the knee of the curve to a point lower than the lowest value to be used. The frequency of reversal is one or two per second. There should be no current in the J coils during demagnetization. After demagnetization, the lowest magnetizing cur-

rent to be used is set and adjustments made as follows: With *SS* on low sensitivity and *SD* on $t-a$, adjust *RA* till upon reversal there is no residual deflection. When adjustment is nearly complete, *SS* is thrown to high sensitivity and adjustment completed; *SD* is then turned to $t-j$ and the current in *J* adjusted until the galvanometer shows no residual deflection when the main and compensating currents are simultaneously reversed. These two adjustments are repeated until both are in adjustment at the same time. The reversals of the magnetizing current during the adjustment are usually sufficient to reduce the iron to a magnetically cyclic state. If necessary, however, a few additional reversals may be made after the adjustment is complete.

When adjustment is obtained for $t-a$ and $t-j$, *SD* is thrown to $t-m$ and *SS* thrown to low sensitivity and a deflection is taken by reversing simultaneously the magnetizing currents and the current in the primary of the mutual inductance. The deflection should be small and in the direction due to t . The induction is then obtained by adding the value corresponding to the current in the mutual inductance primary to that indicated by the deflection. This procedure is preferable to a strictly null method because of the difference in time constants of the mutual inductance circuit and the circuit encircling the iron. The galvanometer index will always show a more or less complex kick which is difficult to interpret. The magnetizing force is given by the formula

$$H = 0.4 \pi n I$$

where n is the number of turns per centimeter along the length of the magnetizing solenoid and I is the magnetizing current in amperes. The standard magnetizing coils used at the Bureau are wound so that

$$H = 100 I$$

Since the test coil has an area somewhat greater than that of the specimen, the observed induction is too great. The correction to be subtracted is $\frac{a-A}{A} H$, where a is the area of the test coil and A is the cross section of the specimen.

Other points on the normal induction curve are obtained in a similar manner. It is not necessary to repeat the demagnetiza-

tion in the determination of successive points at magnetizing forces greater than the preceding. However, if it should be necessary to make a determination at a magnetizing force less than the preceding, demagnetization is necessary.

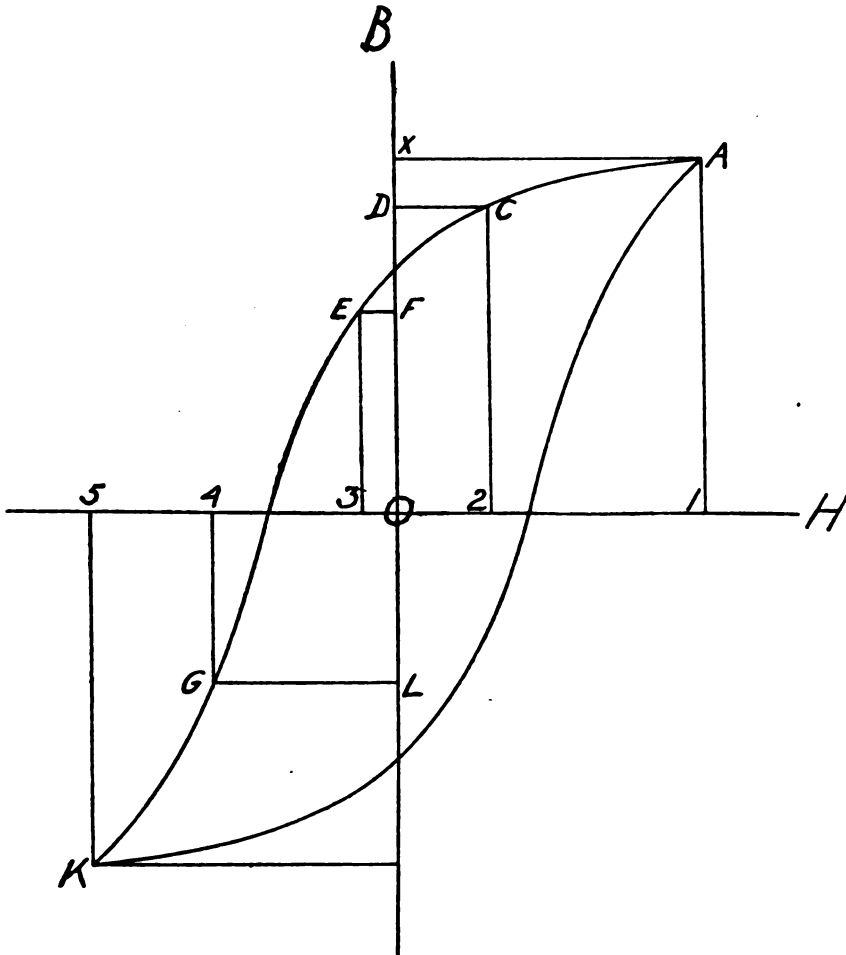


FIG. 4

5. HYSTERESIS DATA

The determination of a hysteresis loop can perhaps be best understood by reference to Fig. 4. Where the iron has been brought to the induction chosen for the tip of the loop and the

cyclic state established its condition is represented by the point A . The magnetizing force is then O_1 and the induction is OX . If the magnetizing force is reversed, the iron is carried along the magnetic path represented by $A E K$ to the point K , where the magnetizing force and induction are each of the same magnitude, but opposite in direction. The change in induction is twice the induction at the tip.

Instead of reversing the magnetizing force we may reduce it to a value represented by the point C . The reduced magnetizing force is then O_2 and the corresponding induction OD . The change in induction which is the quantity indicated by the test coil is then represented by XD . If the apparatus is calibrated to read induction in taking normal induction data by reversals, the readings in each case are to be multiplied by 2 to give the value of change in induction. The value of the induction at any point is the induction at the tip minus the change in induction. Points at the left of the OB axis are obtained by reversing the direction of the magnetizing force at the same time that it is reduced in value. If the change in induction is greater than the induction at the tip, it indicates that the flux has changed in sign as well as in magnitude as at the point G . It is obvious that if the auxiliary bar is not identical with the test bar it may have a loop quite different in shape. This means in general that the ratio of the A current to the T current will not be the same for other points on the loop as for the tip. Besides this the J compensation current will be different at other points. The compensations at the lower points will be correct when in going from the tip there is the same change in induction under the a and j test coils that there is under the t test coil.

The adjustment for compensation is accomplished in the following manner: The adjustment is first made for the tip of the loop and the iron brought to the cyclic state. With switch SD on the point $t-a$ (see Fig. 2) reduce the magnetizing current by closing the switch KT and note the galvanometer deflection. Return to the tip by opening key KT and reverse a few times to regain the cyclic condition. Adjust $R'A$ ser. and $R'A$ par. and operate K_1A and K_2A simultaneously with KT . If there is still a residual deflection, go back to the tip, bring the iron to cyclic state, and try again with a new adjustment of $R'A$ ser. and $R'A$ par. This

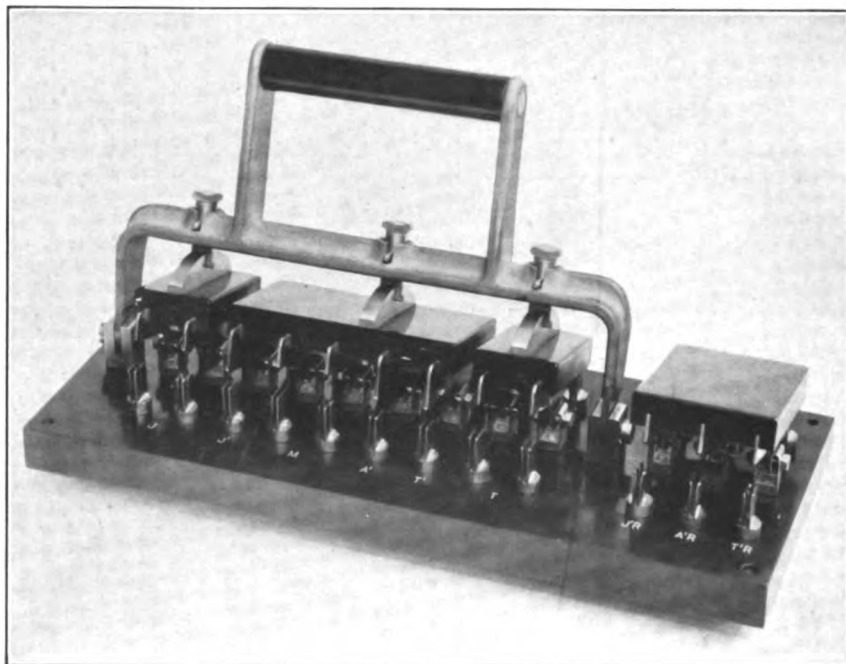


FIG. 5.—*Photograph of special gang switch for Burrows permeameter*

procedure is repeated until upon dropping from the tip there is no residual deflection. (Note that it is possible to make $R'A$ ser. = 0 or $R'A$ par. = ∞ .) Then with switch SD on the point $t-j$ follow out the same course, operating KT , K_1A , K_2A , and KJ simultaneously and making the adjustments with $K'J$. It must be noted that a change of one adjustment may change the other, and it will be necessary to check back and forth from $t-a$ to $t-j$ till both adjustments are good.

The final adjustments are always to be made with the galvanometer at its maximum sensitivity. The reading is taken with switch SD on the point $t-m$ and galvanometer on low sensitivity by operating simultaneously KT , K_1A , K_2A , and KJ and at the same time reversing SM . M should have such a current in its primary that the residual deflection is small and in the direction due to the test coil t encircling the iron. Twice the sum of the reading of the galvanometer and the reading of the mutual inductance is the change in induction. The induction at the tip minus this change is the observed induction at the lower point. The air correction is applied as in the case of normal induction by the formula

$$B_{\text{true}} = B_{\text{obs}} + R(H_1 - H_2)$$

where $R = \frac{a-A}{A}$ as before

and $H_1 = H$ at the tip

and $H_2 = H$ at the lower point

When working near the axis but still on the positive side, it may be necessary to reverse J at the same time that it is reduced. This is accomplished by reversing SJ at the same time that the other switches are operated. To go from the tip to negative values of H , ST is reversed simultaneously with the other operations. The points on a loop can be taken in any order, as each one is taken from the tip after establishing an cyclic condition. It should be noted that the residual induction can not be obtained by simply opening the switches, as in that case there are magnetizing forces acting on the test bar due to the differences in retentivity of the different parts of the magnetic circuit, and thus the magnetizing force is not zero and can not be measured.

This method, in common with all others, assumes specimens magnetically uniform along their length and for accurate work

this requirement must be met. Also for precision work where the highest accuracy is desired it is necessary to control the temperature at some value and always make measurements at that temperature. The standard temperature adopted at the Bureau is

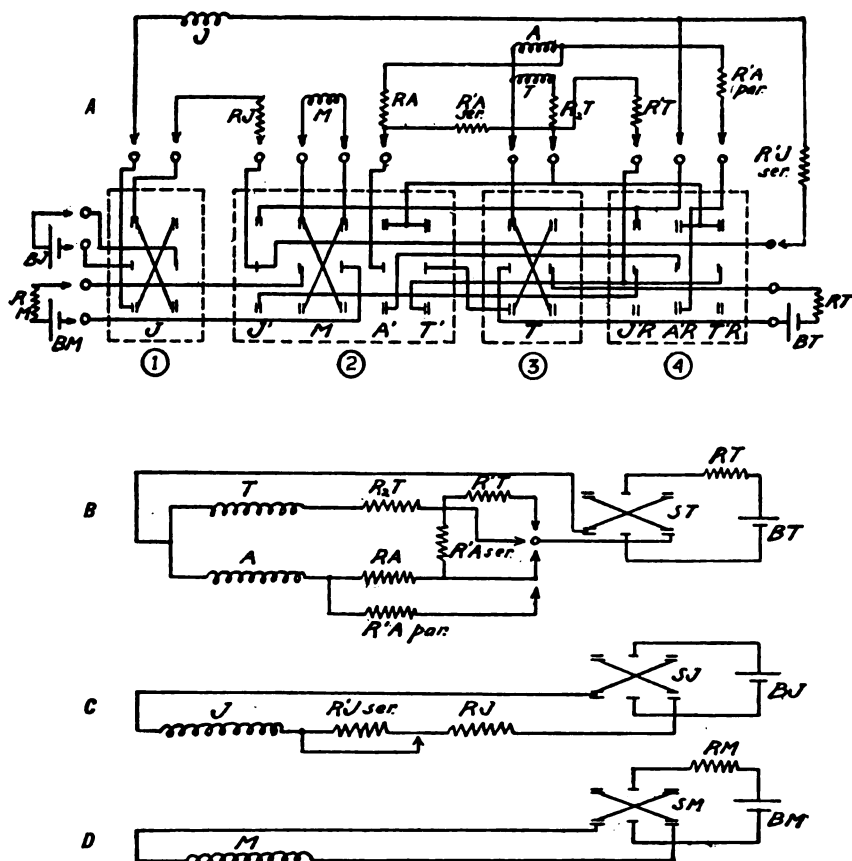


FIG. 6.—Showing diagrams of connections of gang switch for permeability and hysteresis measurements

A, Complete connections: B, main solenoid connections: C, joint coil circuits: D, mutual inductance primary circuit.

25° C, which is maintained by an electrically heated and controlled oil bath.

6. SPECIAL SWITCH AND MANIPULATIONS

The switching operations for the permeameter are greatly facilitated by a specially designed switch shown in Fig. 5. The

diagram *A* of Fig. 6 shows the complete electrical connections of this switch. In diagrams *B*, *C*, and *D* the main solenoid connections, the joint coil circuits, and the mutual inductance primary circuit are shown separately for greater clearness.

During the course of a complete magnetic test the individual switches take the following positions:

Position *A*: Switches 1, 2, 3, and 4, as shown in designs *A* of Fig. 6, are all up and the corresponding electrical connections are as shown in Fig. 7.

Position *B*: Switches 2 and 4 are up; switches 1 and 3 are down. Circuits are same as *A* with currents reversed.

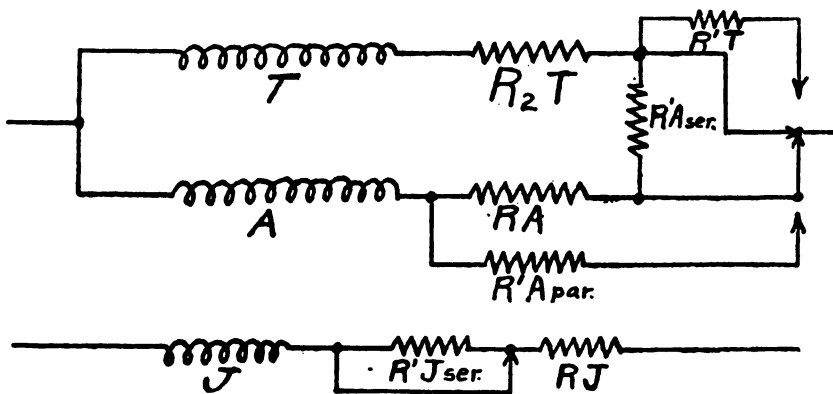


FIG. 7.—Electrical connections when gang switch is in position *A*

Position *C*: Switch 4 is up; switches 1, 2, and 3 are down. Circuits are same as *B*.

Position *D*: Switches 1, 2, 3 are up; switch 4 is down. Circuits are same as *A*.

Position *E*: Switches 1 and 3 are up; switches 2 and 4 are down. Circuits as shown in Fig. 8.

Position *F*: Switch 3 is up; switches 1, 2, and 4 are down. Circuits are same as *E*, but with current in *J* reversed.

Position *G*: Switch 1 is up; switches 2, 3, and 4 are down. Circuits are same as *E*, but with all currents except in *J* reversed.

Position *H*: Switches 1, 2, 3, and 4 are all down. Circuits are same as *E* with all currents reversed.

(NOTE.—Switch 2 also carries the reversing switch for the mutual inductance *M*.)

In the measurement of normal induction and hysteresis the switches are manipulated in the following manner:

NORMAL INDUCTION.—To adjust compensation: Throw switch from position *A* to position *B* and back repeatedly, thus reversing *T*, *A*, and *J*. At the same time adjust resistances *R_A* and *R_J* until there is no residual deflection of the ballistic galvanometer on reversal with switch *SG* on either *t-a* or *t-j*.

To take reading: With switch *SG* on *t-m* and with a suitable adjustment of resistance *R_M*, throw switch from position *A* to position *C*, thus reversing *T*, *A*, *J*, and *M*, and observe galvanometer deflection.

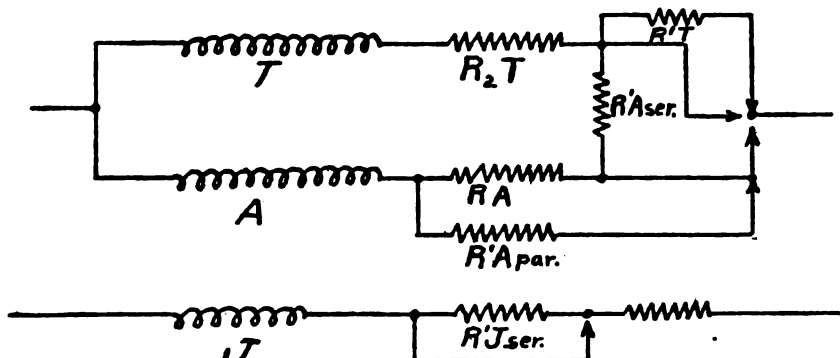


FIG. 8.—Electrical connections when gang switch is in position *E*

HYSTERESIS.—To bring to cyclic state: With resistances adjusted as for normal induction, throw switch from position *A* to position *B* and back repeatedly, thus reversing *T*, *A*, and *J*.

To adjust compensation: Adjust to cyclic state and perform one of the following operations according to the point on the loop desired, and note deflections when *SG* is on *t-a* and *t-j*, respectively. If there is a residual deflection, readjust resistances *R'A ser.*, *R'A par.*, and *R'J ser.*, and repeat the above, including the adjustment to cyclic state. When the adjustment is complete, there will be no residual deflection with switch *SG* on either *t-a* or *t-j*.

To reduce *T*, *A*, and *J*, change ratio of *A* to *T* and reverse *M*; throw switch from position *D* to position *E*.

To reduce *T*, *A*, and *J*, change ratio of *A* to *T*, and also reverse *J* and *M*; throw switch from position *D* to position *F*.

To reduce T , A , and J , change ratio of A to T and reverse T , A , and M but not J ; throw switch from position D to position G .

To reduce T , A , and J , change ratio of A to T and reverse T , A , J , and M ; throw switch from position D to position H .

The ratio of A to T is unchanged if $R'A$ ser. is 0 and $R'A$ infinite; is increased if $R'A$ ser. is 0 and $R'A$ finite; and is increased if $R'A$ ser. is greater than 0 and $R'A$ par. is infinite.

To take a reading: Throw switch as in adjusting the compensation, but with switch SG on and $t-m$ and observe galvanometer deflection. Resistance RM should be adjusted so that the deflection is small and in the direction due to the test coil.

7. FORM OF RECORD

In obtaining magnetic data for a specified set of inductions or of magnetizing forces it is generally sufficient to take observations close to each of the desired points and to scale off the desired values from the curve of observed values. Frequently it takes less time to make two observations, one on each side of the desired value, than it does to make the necessary readjustments for a specific point. The accompanying data sheets and curves illustrate the procedure of a complete set of observations.

V. MEASUREMENT OF CORE LOSS

Standard core-loss determinations at the Bureau of Standards are usually made by means of the Lloyd apparatus. Core-loss determinations are also made according to the specifications of the American Society for Testing Materials.

A. THE LLOYD APPARATUS AND PROCEDURE

1. APPARATUS

The material to be tested is usually submitted in the form of 10 sheets 30 cm (12 inches) square. This material is cut into strips 25.4 by 5 cm (10 by 2 inches). The final cutting to size is done at the Bureau. These are assembled into four bundles, in each of which adjacent strips are separated by strips of press-board of equal width and thickness, but 2 cm shorter. Each bundle is wrapped with gummed paper and is inserted in a solenoid, and the four bundles are then arranged in a square so that

the plan view shows the edges of the strips. (See Fig. 13.) The solenoids are wound upon fiber forms, which are 22.7 cm long, and have inside dimensions 5 by 1 cm. At the corners of the square

BUREAU OF STANDARDS FORM 308

Bureau of Standards

Material *Steel Bar 1/2" diam:*
marked 2A

Test No. *14626*
Date *12-24-13*
Observer *T. A. S.*

DIMENSIONS			Magnetizing coils No. <i>6082</i>		No. of turns in test coil = <i>100</i>					
<i>Depth</i>	<i>1.270</i>		$H = 100 \times I$		Mut. Ind.	<i>P378 S 36.27</i>				
	<i>1.271</i>		Area of test coil (a) = <i>2.16</i>		Cal. Res.	<i>Par. 50 Sec. 9.50</i>				
	<i>1.270</i>		$k = \frac{a - A}{A} = \frac{2.16 - 1.27}{1.27} = .69$		Temperature	<i>25° C.</i>				
	<i>1.271</i>		For Normal Induction, $B_{nm} = B_{an} - k H$							
	<i>1.269</i>		For Hysteresis, $B_{nm} = B_{an} + k (H_n - H_a)$							
Mean	<i>1.270</i>									
Area (A)	<i>1.267</i>									
MAGNETIZING FORCE			INDUCTION							
	I in X I	I in X wt	Cal.		B_{nm}	B_{an}	Air Cor.	B_{nm}	B	H
<i>demagnetized</i>	<i>1.11</i>	<i>1704</i>	<i>305</i>						<i>2000</i>	<i>1.11</i>
	<i>1</i>	<i>1704</i>	<i>303</i>			<i>2008</i>	<i>1</i>	<i>2007</i>	<i>4000</i>	<i>1.59</i>
	<i>1.60</i>	<i>3700</i>	<i>320</i>						<i>6000</i>	<i>2.36</i>
	<i>0</i>	<i>3700</i>	<i>322</i>			<i>4021</i>	<i>1</i>	<i>4020</i>	<i>8000</i>	<i>3.41</i>
	<i>2.41</i>	<i>5714</i>	<i>397</i>						<i>10000</i>	<i>5.15</i>
	<i>1</i>	<i>5714</i>	<i>402</i>			<i>6114</i>	<i>2</i>	<i>6112</i>	<i>12000</i>	<i>6.18</i>
	<i>3.45</i>	<i>7727</i>	<i>322</i>						<i>14000</i>	<i>14.8</i>
	<i>5</i>	<i>7727</i>	<i>320</i>			<i>8048</i>	<i>2</i>	<i>8046</i>	<i>16000</i>	<i>41.6</i>
	<i>5.15</i>	<i>9676</i>	<i>332</i>						<i>18000</i>	<i>132.</i>
	<i>5</i>	<i>9675</i>	<i>337</i>			<i>10010</i>	<i>4</i>	<i>10006</i>	<i>19860</i>	<i>300.</i>
	<i>8.18</i>	<i>11720</i>	<i>241</i>							
	<i>8</i>	<i>11720</i>	<i>283</i>			<i>12002</i>	<i>6</i>	<i>11996</i>		
	<i>14.51</i>	<i>13664</i>	<i>302</i>							
	<i>1</i>	<i>13654</i>	<i>302</i>			<i>13956</i>	<i>10</i>	<i>13946</i>		
	<i>41.10</i>	<i>15727</i>	<i>280</i>							
	<i>0</i>	<i>15727</i>	<i>280</i>			<i>16007</i>	<i>27</i>	<i>15978</i>		
	<i>1279</i>	<i>17714</i>	<i>310</i>							
	<i>9</i>	<i>17710</i>	<i>310</i>			<i>18024</i>	<i>87</i>	<i>17933</i>		
	<i>300</i>	<i>19807</i>	<i>262</i>							
	<i>0</i>	<i>19800</i>	<i>270</i>			<i>20070</i>	<i>210</i>	<i>19860</i>		

FIG. 9.—Photograph of original data sheet for normal induction measurement

short pieces of test material are bent at right angles and interleaved between the strips of adjacent bundles, as shown in the figure. There are as many of these corner pieces as there are test

pieces, and they are graduated in length so as to give a uniform lap of about 2 mm. A clamp is tightened over these laps so as to give a good magnetic joint.

Standard Specification Sheet (1)
March 1905

Bureau of Standards

Material *Magnet Steel*
Bar 1 L

Test No. *17172*

Date *3-18-15*

Observer *T. L. S.*

DIMENSIONS		Magnetizing coils No. <i>7616</i>		No. of turns in test coil = <i>100</i>	
<i>3.722</i>	<i>0.992</i>	$H = 100 \times I$		Mat. Ind.	<i>P378's 93.82</i>
<i>3.720</i>	<i>0.992</i>	Area of test coil (a) = <i>7.90</i>		Gal. Res.	<i>Par. 960 Ser. 3630</i>
<i>3.718</i>	<i>0.993</i>	$\frac{a}{2} = \frac{7.90 - 0.62}{2} = 3.64$		Temperature	<i>17.07°C</i>
<i>3.720</i>	<i>0.992</i>	For Normal Induction, $B_{max} = B_{sat} - a H$			
<i>3.720</i>	<i>0.993</i>	For Hysteresis, $B_{max} = B_{sat} + a (H_1 - H_2)$			
Mean	<i>3.720</i>				
Area (A)	<i>3.69</i>				
MAGNETIZING FORCE		INDUCTION			
	$\frac{100 \times I}{A}$	$\frac{100 \times I}{A}$	Gal.	B_{max}	B_{min}
<i>for life</i>	<i>195</i>	<i>13880</i>	<i>340</i>		
	<i>5</i>	<i>13880</i>	<i>340</i>		
<i>+ 44.2</i>	<i>966</i>	<i>233</i>			
<i>2</i>	<i>966</i>	<i>233</i>	<i>1200</i>	<i>2400</i>	<i>11600</i>
<i>+ 1.6</i>	<i>1697</i>	<i>184</i>			
<i>6</i>	<i>1697</i>	<i>184</i>	<i>1880</i>	<i>3760</i>	<i>10240</i>
<i>- 34.7</i>	<i>2698</i>	<i>302</i>			
<i>7</i>	<i>2698</i>	<i>302</i>	<i>3800</i>	<i>6000</i>	<i>6000</i>
<i>- 52.0</i>	<i>3933</i>	<i>254</i>			
<i>0</i>	<i>3933</i>	<i>250</i>	<i>4165</i>	<i>6370</i>	<i>5630</i>
<i>- 62.3</i>	<i>5958</i>	<i>267</i>			
<i>3</i>	<i>5958</i>	<i>267</i>	<i>6245</i>	<i>12490</i>	<i>1510</i>
<i>- 69.2</i>	<i>8680</i>	<i>400</i>			
<i>2</i>	<i>8680</i>	<i>400</i>	<i>9080</i>	<i>16160</i>	<i>4160</i>
<i>- 65.0</i>	<i>6972</i>	<i>318</i>			
<i>0</i>	<i>6972</i>	<i>316</i>	<i>7290</i>	<i>14580</i>	<i>550</i>
<i>- 93.7</i>	<i>12559</i>	<i>140</i>			
<i>7</i>	<i>12559</i>	<i>142</i>	<i>12700</i>	<i>25400</i>	<i>11400</i>
<i>- 118.6</i>	<i>13202</i>	<i>197</i>			
<i>6</i>	<i>13202</i>	<i>199</i>	<i>13400</i>	<i>26600</i>	<i>12600</i>
<i>- 78.7</i>	<i>10324</i>	<i>276</i>			
<i>7</i>	<i>10324</i>	<i>276</i>	<i>10600</i>	<i>21200</i>	<i>7100</i>

FIG. 10.—Photograph of original data sheet for hysteresis measurement

Each solenoid has two windings. The secondary consists of 121 turns of No. 14 double cotton covered wire. Over the secondary is wound 242 turns of No. 14 double cotton covered wire.

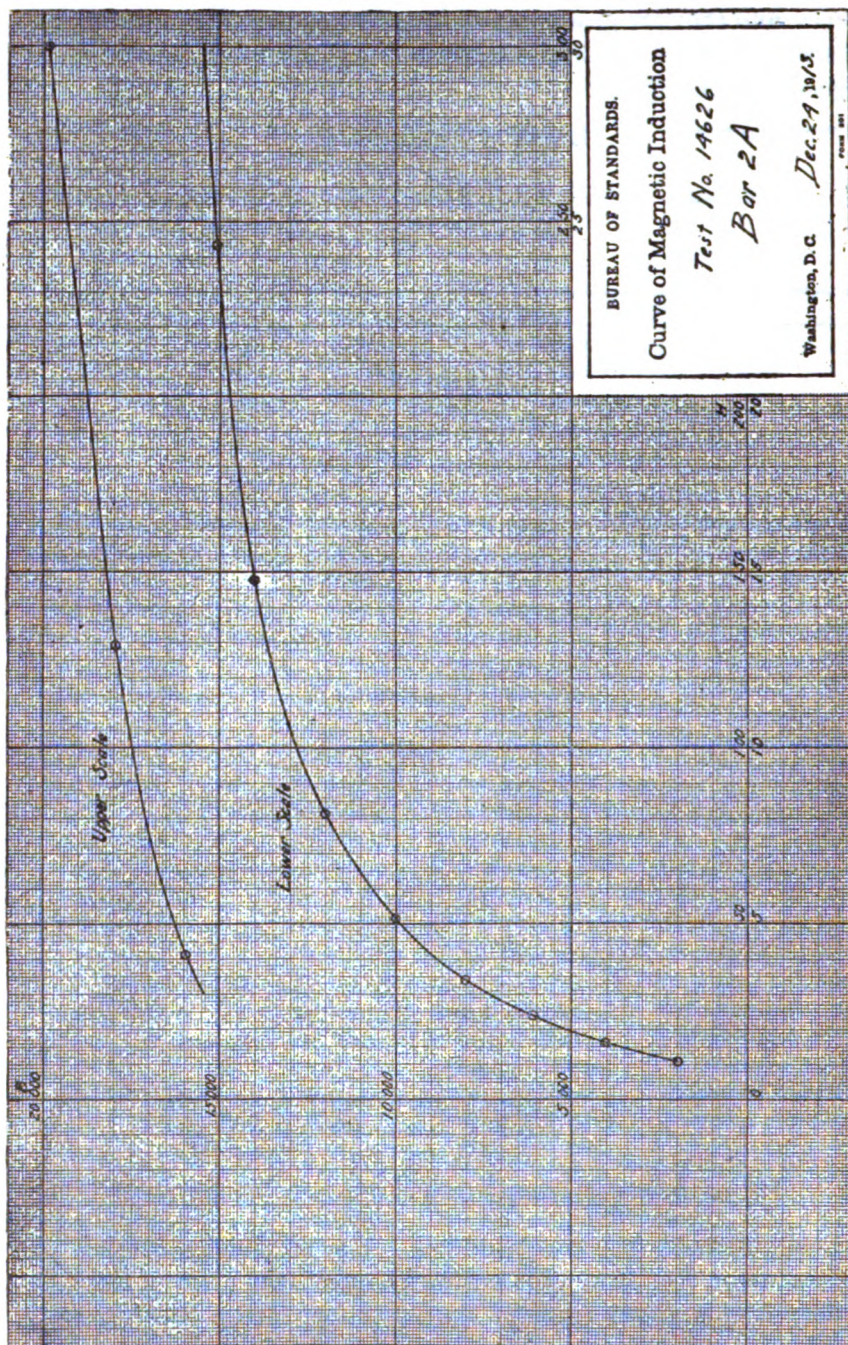


FIG. 11.—Photograph of curve of normal induction as plotted from original data

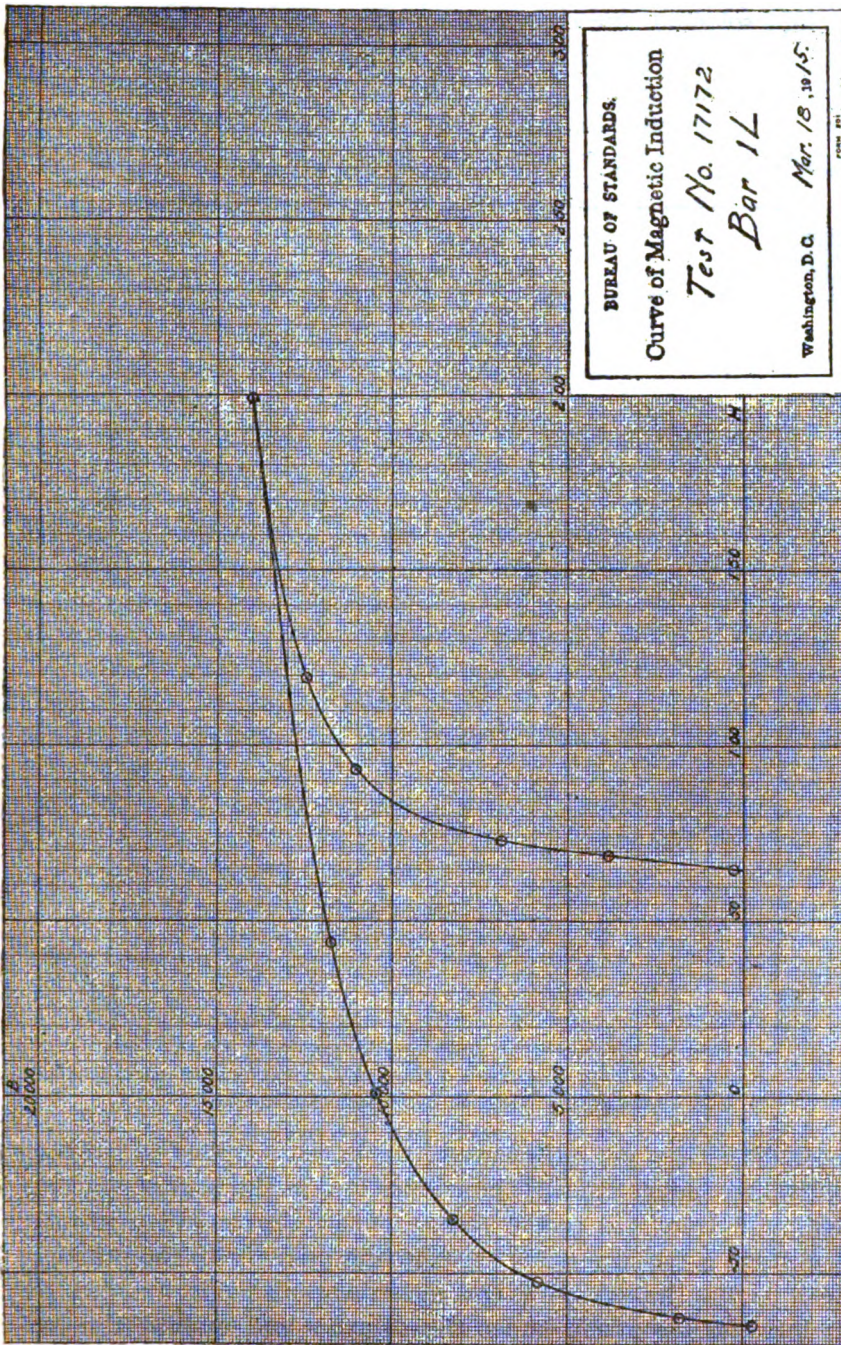


FIG. 12.—Photograph of half of hysteresis loop as plotted from original data

The four solenoids are connected in series, making a total of 968 magnetizing turns and 484 turns in the secondary. The voltmeter and wattmeter which are deflecting mirror electro-dynamometers are connected in parallel to the secondary winding. The magnetizing current traverses the field coils of this wattmeter,

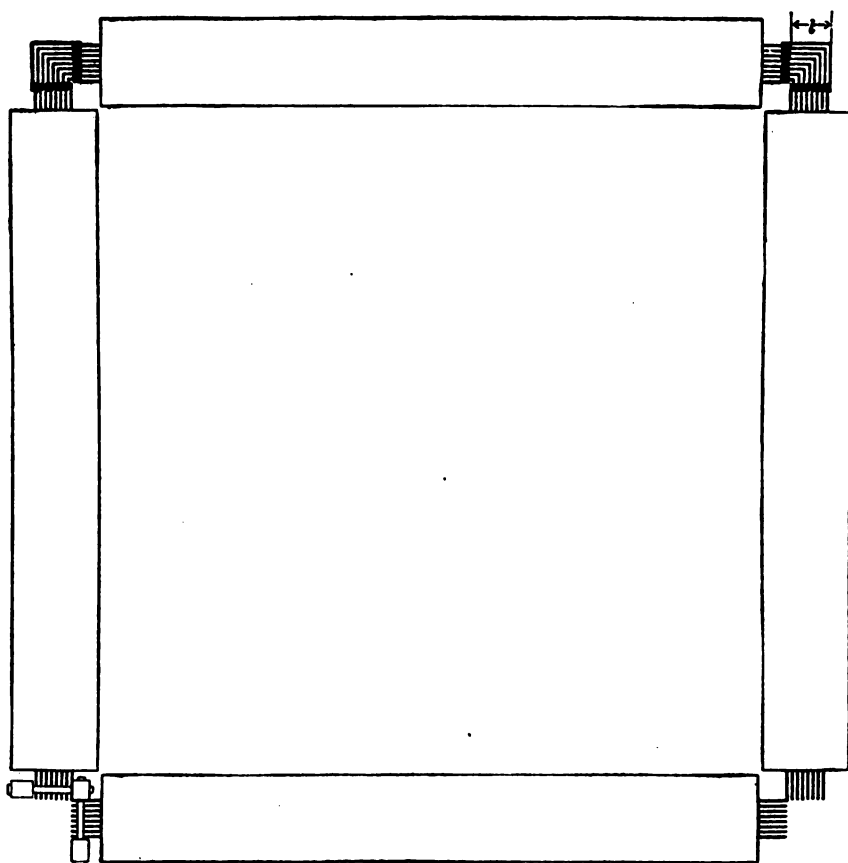


FIG. 13.—Plan of Lloyd apparatus with test pieces in position. Corner pieces have been removed from two and clamps from three corners

whose deflections are a measure of the power supplied to the core and the secondary coils. The copper loss in the primary is thus eliminated from the power measurement. Error will arise only when there is flux threading the core and linked with the primary, which is not linked with the secondary. This is avoided by winding the secondary under the primary and making the two

coextensive in length. The energy in each instrument circuit is obtained by squaring the secondary voltage and dividing by the resistance. By using a small number of turns in the secondary and sensitive instruments these corrections are kept very small and may be calculated from the resistance and voltage.

Voltmeter and wattmeter each have variable multipliers, whose resistances are adjusted to give a suitable deflection in each case. The precision of reading which is usually better than 0.1 per cent, is higher than ordinarily required.

The frequency is determined by a Hartmann and Braun frequency meter, which has been calibrated by the use of a chronograph, or where greatest accuracy is required the chronograph is used directly.

When it is desired to measure the magnetizing current, an ammeter of low resistance can be introduced into this circuit.

On account of the lapping of the corner pieces over the ends of the test pieces the flux density is low in this part of the material, and the results must be corrected therefor. The amount of lap is determined by the relative weights of corner and test pieces as compared with the relative lengths of the two parts of the circuit. When the corner pieces are of the same material as the test pieces, it is assumed that the flux density is halved in the portion of material which laps, and the energy loss is consequently only one-third normal.

B = normal (or average) maximum flux density.

B_1 = maximum flux density at ends of test pieces.

M = mass of test pieces.

m = mass of corner pieces.

l = dimension shown in Fig. 13.

W = measured loss.

$\frac{m}{M}$ = proportional increase in mass of magnetic circuit, due to corner pieces.

$\frac{l}{25.4}$ = proportional increase in length of magnetic circuit, due to corner pieces.

$\frac{m}{M} - \frac{l}{25.4} = c$ = mass of corner pieces which lap, expressed in terms of mass of test pieces.

$2c$ = total material (lapped and lapping iron) in which flux density is $\frac{B_1}{2}$

$2cW \left[1 - \left(\frac{B_1}{2B} \right)^x \right] = 2cWk = \text{correction to } W \text{ for lap, where } x \text{ expresses the law of variation of loss with } B.$

With sufficient accuracy for the purpose, K may be taken as 0.70, so that the correction becomes $1.4 cW$, and the loss per unit mass is $\frac{W}{M+m} (1 + 1.4c)$ or $\frac{W}{(M+m) (1 - 1.4c)}$ with sufficient accuracy. The latter form is the most useful in practice, since a number of observations at different flux densities are usually made upon a single specimen, and the correction may be made once for all to the mass. The quantity $(M+m) (1 - 1.4c)$ may be called the "effective mass."

Corner pieces of different material but of approximately the same quality and thickness may be used with satisfactory and reliable results, providing the constants of the material are known. When using corner pieces of different material from the test pieces, it is necessary to compute the loss in the entire corner pieces and then determine the "effective mass" resulting from the lap reducing the flux in the test pieces. Since the thickness of corner pieces may be different from that of the test pieces, it is necessary to consider this, and the flux at the lap may be considered to divide evenly between the two, or in proportion to their thickness. As the results do not differ materially, we assume that in each lapped part the flux density is half the value in the rest of the material.

Let

$t = \text{thickness of test pieces,}$

$t_1 = \text{thickness of corner pieces,}$

$w = \text{loss per unit mass in corner pieces,}$

and other quantities as before. We neglect leakage which is small; c must now be computed by using for M the mass M_1 of test pieces of same material as corner pieces. The loss in the corner pieces, if there were no lap, would be $w m \left(\frac{t}{t_1} \right)^x$. Considering the effect of lap it is $w (m - 0.7 c M_1) \left(\frac{t}{t_1} \right)^x = W_c$. The correction to the loss in test pieces due to lap is $0.7c (W - W_c)$ and the loss per unit mass is $\frac{W - W_c}{M(1 - 0.7c)}$. If the corner pieces are of approximately

the same thickness as the test pieces, the loss in them is approximately $w(m - 0.7 \text{ cM}_1)$. Here, again, the quantity $(m - 0.7 \text{ cM}_1)$ can be determined once for an entire set of measurements.

2. PROCEDURE

The material is cut into strips of the given dimensions by the use of a sharp machine shear with nearly parallel jaws. The number of strips is determined by the thickness, and for gauge No. 29 amounts to 48. The strips are then weighed, bundled, and mounted in the solenoids. The effective voltage corresponding to any given flux density and frequency is computed from the following relation:

$$E = 4fNn\phi 10^{-8} = \frac{4.44 \times 484 \times 10^{-8}}{101.6\rho} Bn M$$

where n = frequency, ϕ = total flux, f = form factor of secondary emf, and ρ = density.

The dynamometer voltmeter is calibrated for one voltage as determined above, and when taking observations for watt loss, the impressed voltage is adjusted until the same deflection is obtained. For other frequencies and flux densities the resistance in the voltmeter circuit is altered until it is proportional to the product Bn , so that the same deflection is always used. For the lower values of this resistance, the slight correction due to the inductance of the instrument is also made. In computing the power supplied to the voltmeter circuit it may then be remembered that this energy is also proportional to Bn , since the same current is used throughout. An adjustable resistance is used in the potential circuit of the wattmeter, so that the power consumed here is also readily computed. This resistance is adjusted so that the deflection will remain within certain limits. These limits are so chosen that within them the deflections are proportional to the watts.

A direct-connected motor-driven generator gives an emf wave which is sufficiently close to the sinusoidal, and the form factor of the secondary emf has been determined and found sufficiently near to that assumed through the working ranges of flux density at the frequencies used.

The frequencies ordinarily used are 60 and 30 cycles, the latter, being chosen because it makes the separation of hysteresis and

eddy-current losses easy to compute. The motor is supplied with power from a storage battery and the speed is controlled by field resistance. No rheostat is used in the magnetizing circuit. An autotransformer of ample capacity is used to step up or down to approximately the voltage required for the test. The final adjustment of voltage is obtained by adjusting the field resistance of the generator. The electrical connections are shown in Fig. 14. When the voltage has been adjusted to give the proper reading on the voltmeter connected to the secondary circuit the wattmeter is read. An adjustment is then made for a different flux density and readings taken as before. When the magnetizing current is desired an ammeter is included in the magnetizing circuit and its

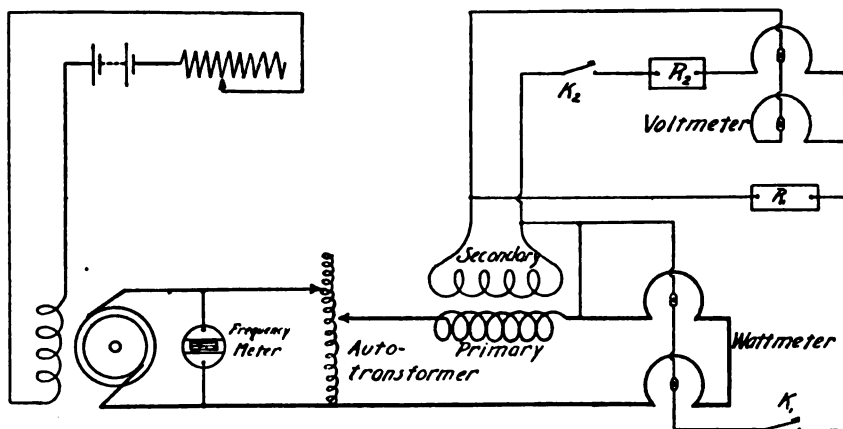


FIG. 14.—Diagram of electrical connections for core loss measurements

indications noted. Whenever a change is made from a higher to a lower flux the current is reduced gradually to the lower value in order to demagnetize the material. Whenever the magnetizing circuit has been broken it is closed through a considerable resistance, which is continuously reduced to zero in order to prevent a large first surge and consequent high magnetization, which would require subsequent demagnetization.

3. SEPARATION OF EDDY-CURRENT AND HYSTERESIS LOSSES

The total loss is separated into two components, due respectively to hysteresis and eddy currents, as follows, using the Steinmetz equation,

$$W = \eta n B^x + \zeta n^2 B^y$$

where the symbols have the same significance as before, η and ζ being constants of the material. By taking observations at two frequencies, n_1 and n_2 , we have

$$\frac{W_1}{n_1} = \eta B^x + \zeta n_1 B^y = a + bn_1$$

$$\frac{W_2}{n_2} = \eta B^x + \zeta n_2 B^y = a + bn_2$$

where a is the hysteresis loss per cycle and bn the eddy-current loss per cycle

$$a = \frac{\frac{W_2}{n_2}n_1 - \frac{W_1}{n_1}n_2}{n_1 - n_2}$$

$$b = \frac{\frac{W_1}{n_1} - \frac{W_2}{n_2}}{n_1 - n_2}$$

If $n_1 = 2n_2$, this computation is greatly simplified; for then

$$bn_2 = \frac{W_1}{n_1} - \frac{W_2}{n_2}$$

$$bn_1 = 2bn_2$$

$$a = 2\frac{W_2}{n_2} - \frac{W_1}{n_1} = \frac{W_2}{n_2} - bn_2$$

While the Steinmetz equation, and consequently this separation, is not accurately in accordance with the facts, the errors are very small in thin sheets. The exponents x and y can be determined by observations at different flux densities. Where the eddy-current loss is small, as in silicon steel, the values of y are subject to greater error.

B. THE A. S. T. M. APPARATUS AND PROCEDURE

The standard specifications of the American Society for Testing Materials for core-loss tests are as follows:

The magnetic circuit shall consist of 10 kg (22 pounds) of the test material, cut with a sharp shear into strips 50 cm (19 $\frac{1}{8}$ inches) long and 3 cm (1 $\frac{1}{8}$ inches) wide, half parallel and half at right angles to the direction of rolling, made up into four equal bundles, two containing material parallel and two containing material at

right angles to the direction of rolling, and finally built into the four sides of a square with butt joints and opposite sides consisting of material cut in the same manner. No insulation other than the natural scale of the material (except in the case of scale-free material) shall be used between laminations, but the corner joints shall be separated by tough paper 0.01 cm (0.004 inch) thick.

The magnetizing winding shall consist of four solenoids surrounding the four sides of the magnetic circuit and joined in series. A secondary coil shall be used for energizing the voltmeter and the potential coil of the wattmeter.

These solenoids shall be wound on a form of any nonmagnetic nonconducting material of the following dimensions:

	Cm
Inside cross section.....	4 by 4
Thickness of wall.....	Not over 0.3
Winding length.....	42

The primary winding on each solenoid shall consist of 150 turns of copper wire uniformly wound over the 42-cm length. The total resistance of the magnetizing winding shall be between 0.3 and 0.5 ohm. The secondary winding of 150 turns of copper wire on each solenoid shall be similarly wound beneath the primary winding. Its resistance shall not exceed 1 ohm.

A voltmeter and the voltage coil of a wattmeter shall be connected in parallel to the terminals of the secondary winding of the apparatus. The current coil of the wattmeter shall be connected in series with the primary winding.

A sine-wave electromotive force shall be applied to the primary winding and adjusted until the voltage of the secondary circuit is given by the equation:

$$E = \frac{4 f N n B M}{4 l D 10^8}$$

in which

f = form factor of primary emf	= 1.11 for sine wave
N = number of secondary turns	= 600
n = number of cycles per second	= 60
B = maximum induction	= 10 000
M = total mass in grams	= 10 000
l = length of strips in centimeters	= 50

$E = 106.6$ volts for high-resistance steel for sine voltage
 $= 103.8$ volts for low-resistance steel for sine voltage

The wattmeter gives the power consumed in the iron and the secondary circuit. The loss in the secondary circuit is given in

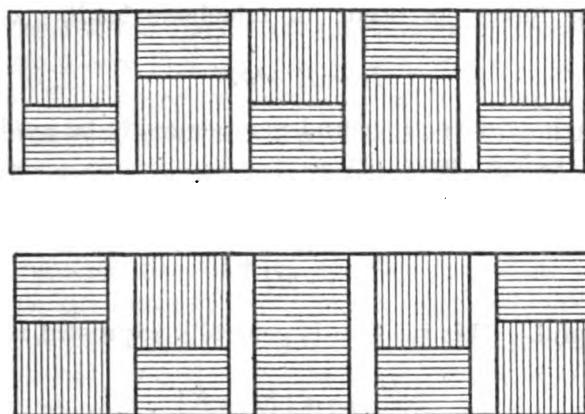


FIG. 15.—*Illustrating the A. S. T. M. method of sampling*

SAMPLING.—The core-loss material shall be cut from two or more sheets taken at random from the shipment. The strips should be distributed symmetrically over the sheet, as nearly as may be practicable. For example, see Fig. 15.

It is recommended that a test sample shall represent not more than 5000 kg (11 000 pounds).

VI. EMPIRICAL FORMULAS

While there are no analytical expressions by means of which exact values of the magnetic induction may be calculated from the magnetizing force, there are several approximate relations which are frequently of service.

1. INDUCTION

The relation

$$B = aH$$

where a is a constant, is sometimes useful in calculations which involve only extremely low magnetizing forces; for example, such magnetizing forces as occur in telephone loading coils. The formula

$$B = aH + bH^2$$

holds through a wider range and may generally be used for magnetizing forces less than unity.

For calculations involving high inductions the formula

$$B = \frac{H}{a + bH} + H$$

is very helpful. This relation is generally expressed in the form

$$\frac{H}{B - H} = a + bH = K'$$

whence it appears that the relation

$$K' = a + bH$$

is linear, and hence suitable for extrapolation. This relation is valuable for the calculation of inductions corresponding to magnetizing forces greater than those which can be easily measured. By it one may readily estimate the induction at a magnetizing force of 1000 gauss from observations at magnetizing forces of 200 and 300 gauss.

For still higher magnetizing forces we may make use of the fact that practical saturation is reached at 1000 gauss and that for greater magnetizing forces the increase in induction is equal to the increase in magnetizing force.

2. HYSTERESIS LOOP

A rough approximation to the area of a hysteresis loop is given by the equation

$$\text{Area of hysteresis loop} = 4 H_c \times B_{\max}.$$

The area thus indicated is too large for material of low permeability and too small for material of high permeability. The maximum error is less than 15 per cent.

3. CORE LOSSES

The formula

$$W = \eta n B^2 + \zeta n^2 B^3 = an + bn^3$$

represents with a fair degree of approximation the relation between the total core loss and the quantities which determine its magnitude. This equation assumes that the induction is the same over different cross sections of the test material, that the exponents are constant, and that the frequency is not too high to permit the material to be magnetized to the same maximum value throughout the cross section.

If this formula is true and the four constants are known, one may calculate the losses at any induction and frequency.

The data required for the separation of the core loss into its eddy-current and hysteresis components (as on p. 32) involve observations under the same conditions of induction and differing only in frequency. With low frequencies of 30 and 60 cycles and the thin material usual in transformer steel, there is no appreciable error.

4. EXPONENTS AND THE RATIO OF VARIATION

The data required for the determination of the exponents, however, involve observations of different inductions and different flux distributions. In addition, the assumption that the exponents are constant requires very careful examination.

It has long been known that an equation of the form

$$W = KB^c$$

will not accurately represent either the hysteresis loss or the total iron losses, and so it has become customary to speak of the exponent as varying slightly so as to force the equation to fit the

experimental values. Numerous determinations have been published to show that the value of the exponent originally given by Steinmetz of 1.6 is only a sufficiently good mean for use over the limited range of inductions used in the design of power transformers, and that not only different kinds of iron give different values, but that for the same sample of iron the exponent varies with the induction.

Unfortunately, however, the methods that have been universally used to determine the exponent have depended upon the implicit assumption that the exponent is a true constant, and hence the values obtained are not actually exponents, but are, in most cases, the logarithmic derivative of W with respect to B , and this becomes the exponent only in the case where it is a constant. In order to make the matter clear it will be well to consider first the methods that have been used to obtain the exponent from the experimental values.²

The method most generally used at present is to plot W against B on logarithmic paper and measure the slope of the resulting curve at various values of B . Still considering c a constant, if we differentiate the equation $W = KB^c$, first taking logarithms of both sides,

$$\begin{aligned}\log W &= \log K + c \log B \\ d(\log W) &= c d(\log B) \\ c &= \frac{d(\log W)}{d(\log B)}\end{aligned}\tag{1}$$

which shows that c is the slope of the logarithmic curve. An equally accurate but less convenient method may be used with ordinary cross-section paper. Equation (1) may be written in the form

$$c = \frac{\frac{dW}{W}}{\frac{dB}{B}} = \frac{B}{W} \cdot \frac{dW}{dB}\tag{2}$$

from which the value of c at any point of the curve is seen to depend upon the values of W , B , and the slope of the curve at the

² This discussion of exponents and the ratio of variation is taken almost verbatim from a paper by P. G. Agnew on "A study of the current transformer with particular reference to iron loss," *Bull., Bureau of Standards*, 7, p. 423; 1911 (Scientific Paper No. 164).

point. These three quantities must be expressed in consistent units, as the slope $\frac{dW}{dB}$ is no longer a simple geometrical ratio as in equation (1), but has the dimensions of $\frac{W}{B}$. Another method which is often used is to solve for c from the values at two points of the curve. Thus if

and
$$\left. \begin{aligned} W_1 &= K B_1^c \\ W_2 &= K B_2^c \end{aligned} \right\} \quad (3)$$

then
$$c = \frac{\log \frac{W_1}{W_2}}{\log \frac{B_1}{B_2}} = \frac{\log W_1 - \log W_2}{\log B_1 - \log B_2} \quad (4)$$

Common logarithms may be used in either (1) or (4).

None of these methods is correct if we are dealing with a variable exponent, for then in differentiating to get (1) and (2) we should have had to take account of the variation of c with respect to B , and evidently (4) could not have been deduced at all since we should have had different values of c in (3). This will appear more clearly in an examination of the general case in which

$$W = K B^z \quad (5)$$

where the exponent z is now a variable. It may first be said that suggestions have been made that K should be considered to vary so as to fit the observations to some sort of a curve, and some writers have even treated both the coefficient and the exponent as variables, which is manifestly absurd. To consider that we have an exponent which varies slightly about a mean introduces complications, as will be shown, which greatly limits its usefulness, while any attempt to treat such a formula containing a variable coefficient can accomplish nothing since in its very simplest form the exponent would reduce to unity which merely brings us back to the measured values of B and W .

To determine, then, the relations which follow by treating the coefficient as constant and the exponent as a variable, write (5) in the logarithmic form,

$$\log W = \log K + z \log B$$

Differentiating,

$$\begin{aligned}\frac{dW}{W} &= \log B \, dz + z \frac{dB}{B} \\ \frac{\frac{dW}{W}}{\frac{dB}{B}} &= z + B \log B \frac{dz}{dB}\end{aligned}\quad (6)$$

The left-hand member of this equation is the logarithmic derivative of W with regard to B , or the slope of the curve obtained by plotting W against B on logarithmic coordinate paper. If z is a constant the last term becomes zero, the curve becomes a straight line, and the slope of the logarithmic curve is the exponent. But if z is not zero the value of the exponent from equation (6) is

$$z = \frac{\frac{dW}{W}}{\frac{dB}{B}} - B \log B \frac{dz}{dB} \quad (7)$$

This shows that the logarithmic derivative is not the same as the exponent, as is tacitly assumed in the methods in common use in the determination of the exponent where the latter varies. The last term in (7) is entirely neglected in the methods which make use of either logarithmic or ordinary coordinate paper, as what is measured in these cases is merely the logarithmic derivative. Similarly the method of solving for the exponent by using values at two points of the curve will not give even the average value of the exponent over the range taken, as it is generally believed to do, for by equation (4) the quantity thus given is

$$\frac{\log \frac{W_1}{W_2}}{\log \frac{B_1}{B_2}}$$

Now, if we take B_2 very near B_1 we may replace W_1 , W_2 , B_1 , B_2 , by $W + \delta W$, W , $B + \delta B$, and B .

$$\frac{\log \frac{W_1}{W_2}}{\log \frac{B_1}{B_2}} = \frac{\log \frac{W + \delta W}{W}}{\log \frac{B + \delta B}{B}}$$

$$= \frac{\log \left(1 + \frac{\delta W}{W} \right)}{\log \left(1 + \frac{\delta B}{B} \right)}$$

and we may replace $\log \left(1 + \frac{\delta W}{W} \right)$ by $\frac{\delta W}{W}$, which is the first term in its expansion, and similarly for B .

This gives

$$\frac{\frac{\delta W}{W}}{\frac{\delta B}{B}}$$

which is the logarithmic derivative. Hence, this method gives a result which approaches that given by the other methods, namely, the slope of the logarithmic curve instead of the exponent.

The slope of the logarithmic curve is, however, of much more practical importance than the true exponent, for the greatest use of such empirical relations is as interpolation formulas. The logarithmic derivative, which is referred to hereafter as the "ratio of variation," is an exceedingly convenient form for interpolation, since for small variations it is the ratio of the percentage change in the dependent variable to the percentage change in the independent variable.

In order to bring out graphically the differences that may exist between the exponent and the ratio of variation in geometrical curves of the general parabolic form and whose exponents are of the order of magnitude of those met with in iron losses, in Fig. 16 the curve $y = x^{2+\frac{1}{x}}$ together with the exponent and the ratio of variation have been plotted. This curve was chosen, as the values of the exponent and the ratio of variation are around 2 and both decrease with increasing values of x . In Fig. 17 the curve $y = x^{1+0.1x}$ together with the exponent and the ratio of variation are plotted. It will be seen that when the exponent is 2 the ratio of variation is 4.3.

Since the last term in equation (6) is positive, it follows that the ratio of variation will be greater than the exponent when the latter is increasing, and less when the exponent is decreasing.

Consequently the exponent curve lies above in Fig. 16 and below in Fig. 17.

If in the case of a curve whose exponent is changing slowly we choose two points of reference and solve for the exponent as if it were constant, one might expect to get a value somewhere near the mean of the actual values at the given points, but such is not the case. It may be either greater or less than the actual value at either limit, according to circumstances. A more surprising result of the variation of the exponent is the effect that such a method has in making large changes in the coefficient. For example, if

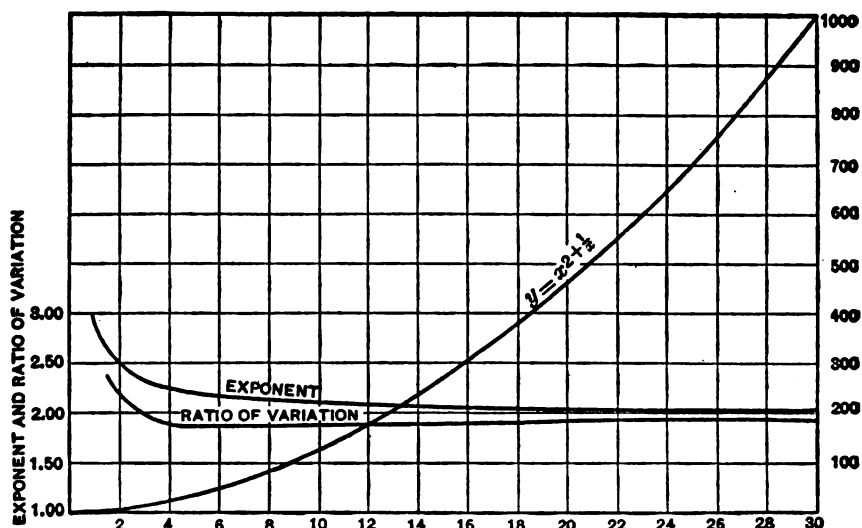


FIG. 16.—Showing the difference between the exponent and the ratio of variation in the curve $y = x^{2+\frac{1}{x}}$

we consider the curve of Fig. 16 as an experimental curve and attempt to determine the coefficient and exponent by this method, which is the one that has been most frequently used in discussing changes in the Steinmetz exponent, we get the following results. The computed exponents are nearly identical with the ratio of variation.

Limits used	Actual curve at midpoint of range	Computed equation
$x=6$ to $x=8$	$y=x^{1.7}$	$y=0.075 x^{1.66}$
$x=8$ to $x=10$	$y=x^{1.6}$	$y=0.0137 x^{1.66}$

The matter is not, however, so serious as these results indicate at first sight, for while the exponents have increased the coefficient has changed from unity to the small fractions, and either of the computed curves will give fair approximations throughout the small range for which it is computed. Yet it does emphasize the

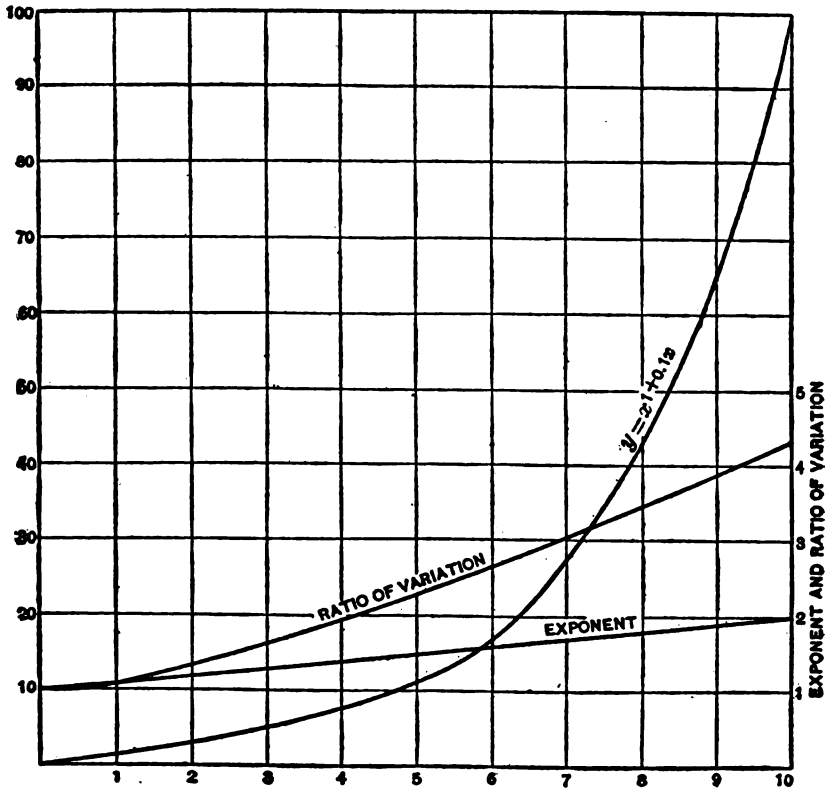


FIG. 17.—Showing the difference between the exponent and the ratio of variation in the curve $y = x^{1+0.12}$

desirability of abandoning the use of the word "exponent" as applied to the results of such processes.

On the whole, the determination of the actual exponent is of little practical importance. It is much more difficult to determine than the ratio of variation, it depends upon the unit in which the independent variable is expressed, and after it is once determined its use, as in interpolation, requires logarithms even for small intervals. The ratio of variation, that is, the slope of

the logarithmic curve, is much more convenient to use in interpolating over small intervals. The fact that a constant exponent is the same as the ratio of variation has led to a failure to distinguish between them when the exponent is not constant, and this has introduced considerable confusion, not only in the literature of iron losses, but in the other fields in which the same ideas are made use of. Many attempts have been made to measure the variation of the exponent by methods which assume a constant exponent.

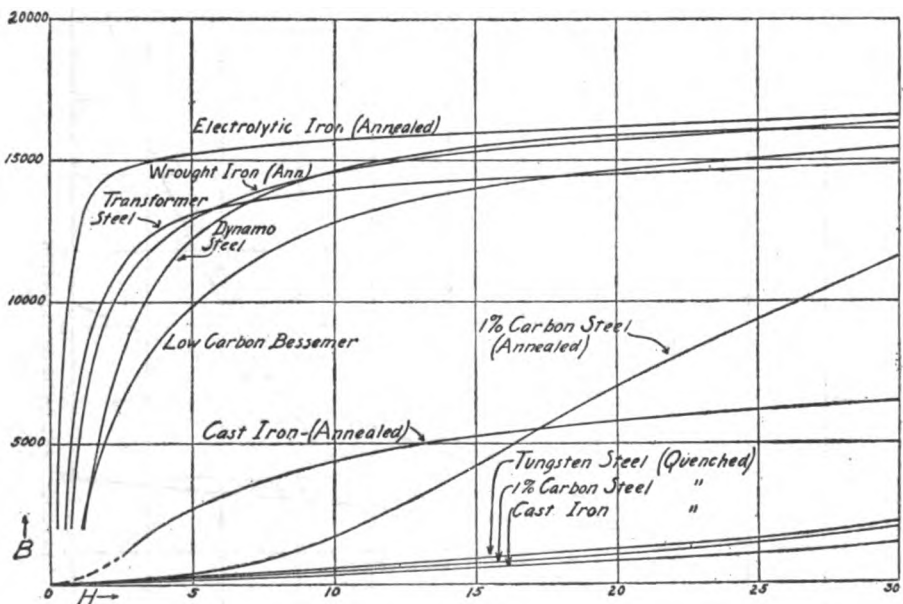


FIG. 18.—Showing typical normal induction curves for the usual commercial magnetic materials for magnetizing forces less than 30 gauss

VII. TYPICAL CURVES AND DATA

The following curves are given to show the characteristics which are commonly obtained in ordinary commercial magnetic materials. Figs. 18, 19, and 20 show the magnetic characteristics of some of the materials which are commonly employed in the construction of magnetic and electromagnetic apparatus. These include electrolytic iron, wrought iron, ordinary dynamo sheet, low-carbon bessemer (about 0.17 per cent C), high-silicon sheet (about $3\frac{1}{2}$ per

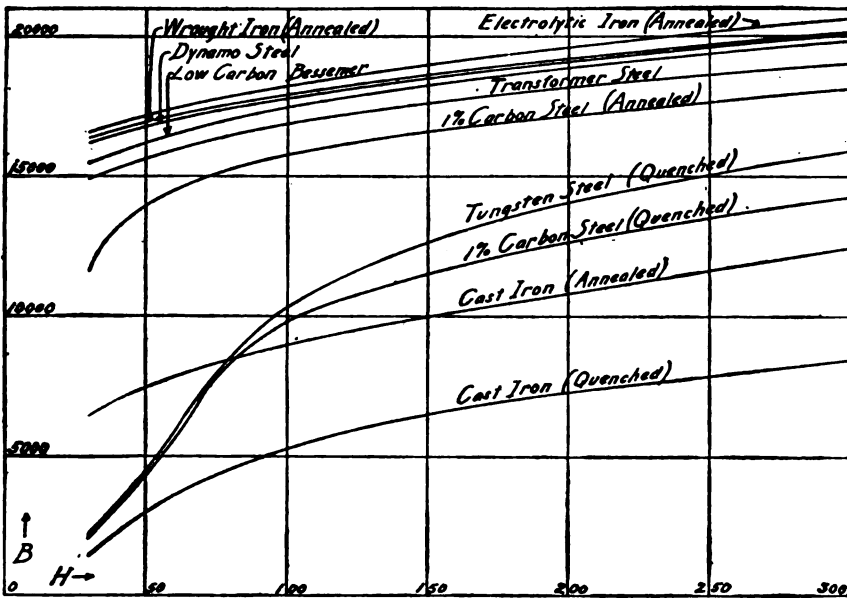


FIG. 19.—Showing typical normal induction curves for the usual commercial magnetic materials for magnetizing forces between 30 gauss and 300 gauss

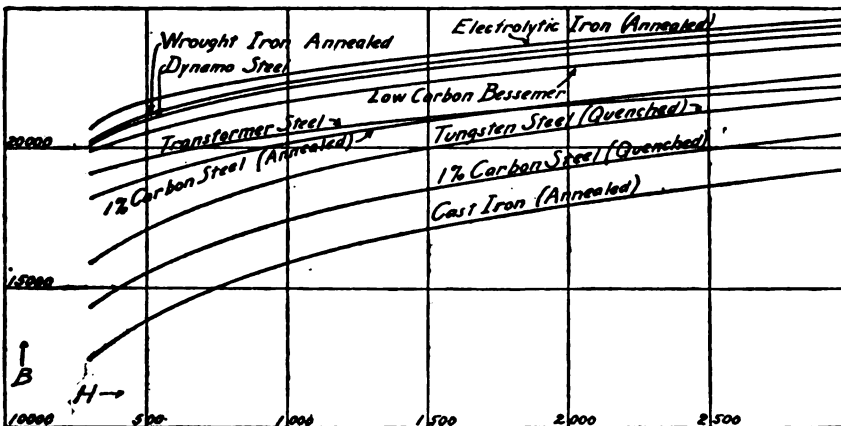


FIG. 20.—Showing typical normal induction curves for the usual commercial magnetic materials for magnetizing forces between 300 gauss and 3,000 gauss

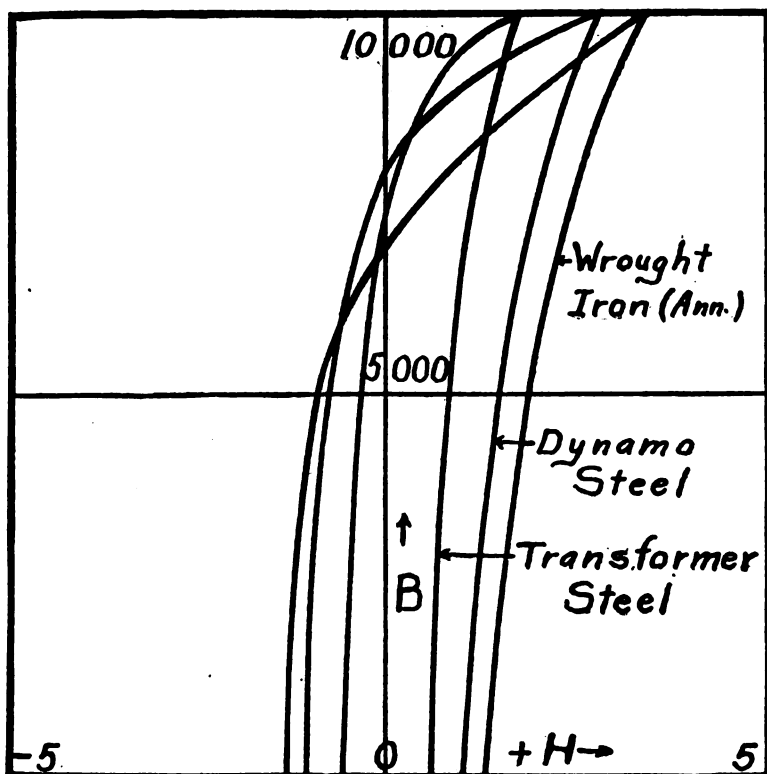


FIG. 21.—Showing typical hysteresis half loops for the usual commercial magnetic materials used in transformer and armature construction

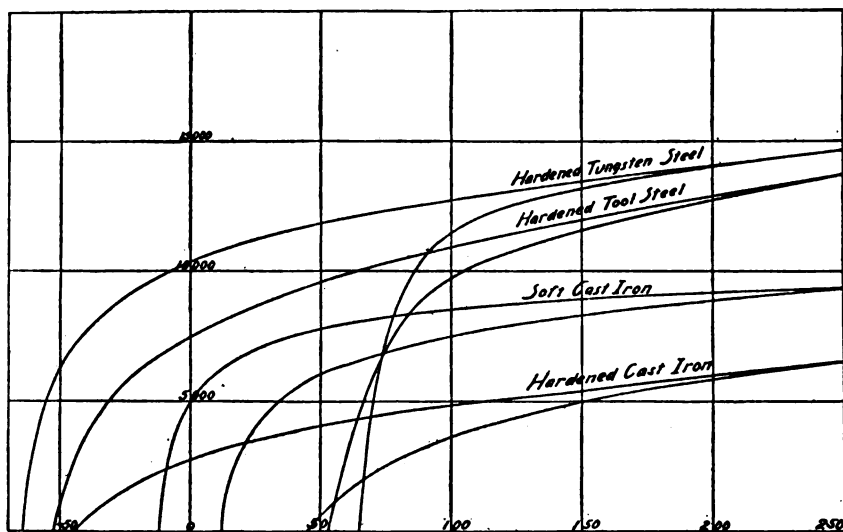


FIG. 22.—Showing typical hysteresis half loops for the usual commercial magnetic materials used for permanent magnets

cent Si), annealed and hardened high-carbon steels (about 1 per cent C), tungsten steel, and cast iron. Fig. 21 shows hysteresis loops from a tip of 10 000 gauss for dynamo steel, high-silicon steel, and wrought iron, which materials are largely used in electromagnetic cores, transformers, and armatures. Fig. 22 gives hys-

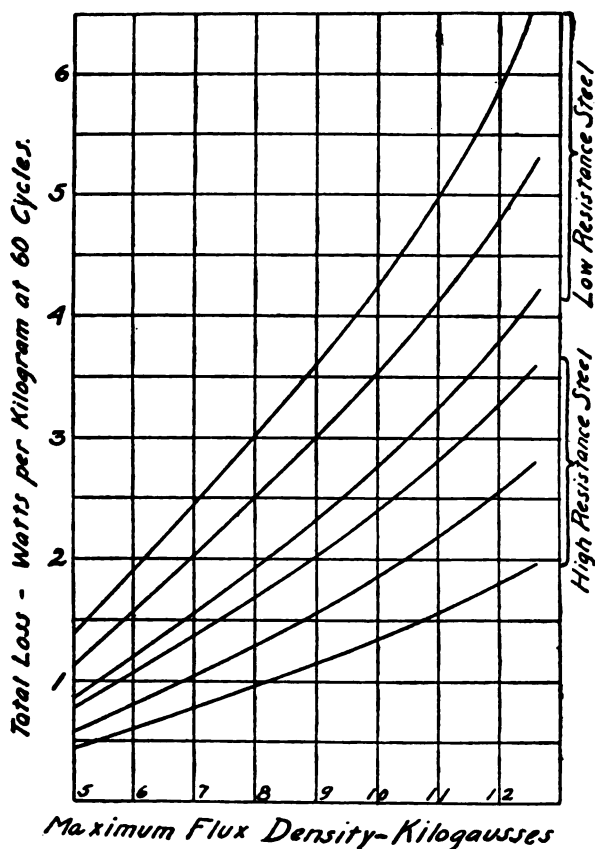


FIG. 23.—Showing typical curves of total core losses for the usual materials used in transformer and armature construction

teresis loops for cast iron both in the hardened and in the soft state and for tungsten magnet steel. Fig. 23 gives the values of the total core loss at 60 cycles for different values of the maximum induction for the steels ordinarily used in alternating-current apparatus. These steels are generally grouped as high-resistance steels and low-resistance steels. High-resistance steels have a

resistivity of between 3 and 5 ohms per metergram. Low-resistance steels have a resistivity more nearly 1 ohm per metergram. We may assume a value of 2 ohms per metergram as the dividing point between high and low resistance steels. This makes a very useful distinction for commercial steels. High-resistance steels contain about 3 per cent of silicon and have a low specific gravity (about 7.5) and a low core loss. Low-resistance steels are relatively pure iron and have a higher specific gravity (about 7.7) and a core loss approximately double that of the high-resistance materials.

The magnetic susceptibility of the so-called nonmagnetic materials is very small. The most convenient unit is one-millionth as large as the usual cgs unit. In terms of this unit the values of susceptibility extend from about +400 for solid oxygen to -14 for the diamagnetic bismuth. The susceptibilities given by different observers differ quite widely. This is probably due to the difficulty in getting pure materials. Traces of iron which are too small to be measured by the regular chemical methods will frequently mask entirely the true magnetic properties of the pure material, and consequently an investigator may report a substance as paramagnetic and a later investigator working with purer materials may report it as diamagnetic. The accompanying table gives the most probable values of susceptibility available at the present time. The susceptibility as usually defined is κ_v , sometimes called the volume susceptibility. The mass susceptibility κ_m is this value divided by the density.

Magnetic Susceptibilities

Name	Symbol	$10^6\chi_v$	$10^6\chi_m$	Name	Symbol	$10^6\chi_v$	$10^6\chi_m$
Aluminium.....	Al.....	+ 1.8	+ 0.6	Mercury.....	Hg.....	- 2.3	- 0.2
Antimony.....	Sb.....	- 4	.....	Molybdenum.....	Mo.....	.....	+ 0.04
Argon, 1 atm.....	A.....	- 0.10	.....	Nickel.....	Ni.....	.....	.....
Arsenic.....	As.....	.....	- 0.3	Nickel.....	NiCl ₂.....	.....	+35
Barium.....	Ba.....	.....	- 0.3	Niobium.....	Nb.....	.....	+ 1.3
Beryllium.....	Be.....	.....	+ 0.8	Nitrogen, 1 atm.....	N.....	+ 0.001	.....
Bismuth.....	Bi.....	-14	- 1.0	Osmium.....	Os.....	.....	.....
(Temp. 270° C.)	Bi fluid.....	.....	- 0.01	Oxygen, 1 atm.....	O.....	+ 0.12	.....
Boron.....	B.....	.....	- 0.7	O liquid.....	O liquid.....	.....	260
Bromine.....	Br.....	- 1.4	- 0.4	O solid.....	O solid.....	.....	400
Cadmium.....	Cd.....	.....	- 0.16	Palladium.....	Pd.....	+60	+ 5
Cæsium.....	Cs.....	- 0. (?)	- 0. (?)	Phosphorus.....	P white.....	.....	- 0.9
.....	CsCl.....	.....	- 0.28	.....	P red.....	.....	- 0.7
Calcium.....	Ca.....	.....	.....	Platinum.....	Pt (pure).....	1	.....
.....	CaO.....	.....	- 0.27	Potassium.....	K.....	.....	+ 0.5
.....	CaCl ₂.....	.....	- 0.39	.....	KCl.....	.....	- 0.5
Calcium carbon- ate (marble).....	CaC ₂	-0.6 to -0.9	.....	Praseodymium.....	Pr.....	.....	.....
Carbon.....	.....	- 8	.....	.....	PrCl ₃.....	.....	+14
Arc carbon.....	.....	.....	- 2	Rhodium.....	Rh.....	+13	+ 1.5
Diamond.....	.....	.....	- 0.4	Selenium.....	Se.....	- 0.5	.....
Carbon dioxide.....	CO ₂.....	.....	+ 0.017	Silicon.....	Si.....	.....	- 0.1
1 atm.....	.....	.....	.....	Quartz.....	SiO ₂	- 1.2	.....
Cerium.....	Ce.....	.....	.....	.....	Glass.....	-0.9 to -1.3	.....
.....	CeCl ₃.....	.....	+5 to +10	Silver.....	Ag.....	- 1.5	- 0.2
.....	.....	.....	+ 4	Sodium.....	Na.....	.....	+ 0.52
Chromium.....	Cr.....	.....	.....	.....	NaCl.....	.....	- 0.41
Chlorine.....	Cl.....	- 0.007	- 0.59	Strontium.....	.....	.....	.....
Cobalt.....	Co.....	.....	.....	.....	SrCl ₂.....	.....	- 0.44
.....	CeCl ₃.....	.....	+90	Sulphur.....	S.....	- 0.8	- 0.5
Copper.....	Cu.....	- 0.7	- 0.09	Tantalum.....	Ta.....	.....	+ 0.9
.....	CuO.....	.....	+ 0.73	Tellurium.....	Te.....	- 1.5	- 0.3
.....	CuSe ₄.....	.....	+ 6.5	Thorium.....	Th.....	.....	+ 0.2
.....	Crys.....	.....	.....	Tin.....	Sn.....	- 0.35	- 0.03
Gold.....	Au.....	- 3.1	- 0.15	.....	Sn gray.....	.....	- 0.4
Helium, 1 atm.....	He.....	- 0.002	.....	.....	Sn fluid.....	.....	- 0.04
Hydrogen, 1 atm.....	H.....	+ 0.005	.....	Titanium.....	Ti.....	.....	+ 3
Indium.....	In.....	.....	+ 0.1	Tungsten.....	W.....	.....	- 0.33
Iodine.....	I.....	.....	- 0.35	Vanadium.....	V.....	.....	+ 1.7
Iridium.....	Ir.....	+ 4.9	+ 0.2	Zinc.....	Zn.....	- 0.9	- 0.1
Iron salts.....	FeCl ₃.....	.....	+90	Zirconium.....	Zr.....	.....	- 0.4
.....	FeCl ₃.....	.....	+90	.....	.....	.....	.....
.....	FeSe ₄ + 7H ₂ O.....	+80	.....	Air, 1 atm.....	.....	+ 0.032	.....
Lead.....	Pb.....	- 1.1	- 0.1	Ebonite.....	.....	+ 1	.....
Lithium.....	Li.....	.....	+ 0.38	Paraffin.....	.....	.....	- 0.9
Magnesium.....	Mg.....	.....	+ 0.56	Shellac.....	.....	- 0.4	.....
Manganese.....	Mn.....	.....	+15	Water.....	H ₂ O.....	- 0.8	.....
.....	.....	.....	.....	Wood.....	.....	-0.2 to -0.5	.....

Most organic compounds are diamagnetic and have a mass susceptibility between -0.5 and -0.9 .

VIII. PUBLICATIONS ON MAGNETIC SUBJECTS

The following papers on magnetic subjects have been published by the Bureau. They are issued in pamphlet form as Scientific Papers and will be sent upon request. They may be designated by the numbers which precede the titles in the list. A complete list of the technical publications of the Bureau, with brief abstracts of contents, will also be sent upon application.

SCIENTIFIC PAPERS

- No. 38. Experiments on Heusler magnetic alloys; by K. E. Guthe and L. W. Austin.
- No. 78. On the best method of demagnetizing iron in magnetic testing; by C. W. Burrows.
- No. 87. Apparatus for the determination of the form of a wave of magnetic flux; by M. G. Lloyd and J. V. S. Fisher.
- No. 88. Effect of wave form upon the iron losses in transformers; by M. G. Lloyd.
- No. 106. Dependence of hysteresis upon wave form; by M. G. Lloyd.
- No. 108. Errors in magnetic testing with ring specimens; by M. G. Lloyd.
- No. 109. The testing of transformer steel; by M. G. Lloyd and J. V. S. Fisher.
- No. 117. The determination of the magnetic induction in straight bars; by C. W. Burrows.
- No. 164. A study of the current transformer with particular reference to iron loss; by P. G. Agnew.
- No. 228. An experimental study of the Koepsel permeameter; by C. W. Burrows.
- No. 245. Temperature coefficient of magnetic permeability within the working range; by R. L. Sanford.

CIRCULAR

- No. 6. Fees for electric, magnetic, and photometric testing.



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MAGNETIC TESTING

CIRCULAR OF THE BUREAU OF STANDARDS, No. 17

DEPARTMENT OF COMMERCE
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MAGNETIC QUANTITIES, UNITS, SYMBOLS, AND EQUATIONS

Magnetic Quantities and Units

Quantity	Symbol	Name of Unit
Magnetomotive force	F	gilbert
Magnetic flux	φ	maxwell
Magnetic reluctance	R	oersted
Magnetizing force	H	gilbert per cm
Magnetic induction	B	gauss
Magnetic permeability	μ	
Intensity of magnetization	J	
Magnetic susceptibility	κ	

Equations

$$\begin{array}{lll}
 F = 0.4 \pi N I & H = \frac{dF}{dl} & H = 0.4 \pi n I \\
 e = N \frac{d\varphi}{dt} 10^{-8} & B = \frac{\varphi}{S} & J = \frac{B - H}{4\pi} \\
 \varphi = \frac{F}{R} & \mu = \frac{B}{H} & \kappa = \frac{J}{H}
 \end{array}$$

N = number of turns	n = number of turns per cm l = length in cm t = time in seconds
I = current in amperes	
e = electromotive force in volts	
S = cross section in cm^2	

A. S. G. Hunt.
gfr
2-17-1927

MAGNETIC TESTING

ABSTRACT

The commercial importance of magnetic testing is continually increasing. New and improved magnetic materials are being developed and more attention is being given to the specification and testing of materials used primarily for their magnetic properties. In order to promote uniformity in specification and testing of magnetic materials this circular gives a brief discussion of magnetic quantities and characteristics of materials, and outlines the various methods used by the bureau for magnetic testing.

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I. INTRODUCTION

The work of the Bureau of Standards in magnetic testing may be considered under three heads—(a) investigation and development of testing methods, (b) standardization of testing apparatus, and (c) magnetic testing of materials.

In view of the rapidly increasing amount of magnetic testing that is being done, particularly by commercial laboratories, it is very important that reliable information should be available as to the accuracy and suitability of various methods for definite purposes. There is no universal method which is applicable for all purposes, each of the methods in present use having its own peculiar limitations as to form of specimen, range of measurements, or properties of the material to be tested. In this phase of the work, therefore, it is the aim to determine the possibilities and limitations of existing methods and to develop new ones as need arises.

In the field of standardization, the work consists in the selection and preparation of suitable test specimens which, when their magnetic properties have been accurately determined, are used as magnetic standards for the calibration of testing apparatus. The proper selection and preparation of such standards is very important because errors of considerable magnitude can often be attributed to irregularities in the specimens rather than to errors inherent in the testing apparatus. It is obvious that, in such cases, erroneous conclusions may be arrived at as to the accuracy of a particular instrument or method.

A considerable amount of magnetic testing of a more or less routine nature is done in the course of investigations on the magnetic properties of materials and for outside parties requesting such tests. In the latter case, a reasonable fee is charged. The work for outside parties is limited, in general, to tests for the purpose of checking the accuracy of testing apparatus or for the settling of disputes arising from lack of agreement between different laboratories. Routine acceptance tests which can be made by commercial testing laboratories of good standing are not made by the bureau except for special reasons.

II. MAGNETIC QUANTITIES AND UNITS

The quantities most commonly used in magnetic testing are magnetomotive force, magnetic flux, magnetic reluctance, magnetizing force, magnetic induction (flux density), magnetic permeability, intensity of magnetization, and magnetic susceptibility.

1. MAGNETOMOTIVE FORCE

One common means by which objects may be magnetized is a solenoid in which an electric current is flowing. The total magnetizing influence is expressed in terms of the number of turns of wire and the value of the current. This magnetizing influence is called the magnetomotive force (F) and the cgs unit is called the gilbert. If N is the total number of turns and I is the current in amperes, then the magnetomotive force in gilberts is

$$F = 0.4 \pi N I$$

this relationship serves to define the gilbert.

2. MAGNETIC FLUX

When a substance is magnetized, it is said to carry a magnetic flux (ϕ). The cgs unit of magnetic flux is called the maxwell and its magnitude is such that when the flux linked with a single turn of wire varies at the rate of 10^8 maxwells per second, an electromotive force of 1 volt is induced in the wire. This relationship serves to define the maxwell.

3. MAGNETIC RELUCTANCE

The value of magnetic flux resulting from the influence of a given magnetomotive force is limited or determined by the magnetic reluctance (R) of the magnetic circuit. The cgs unit of magnetic reluctance is called the oersted. The relationship is expressed by the so-called Ohm's law of the magnetic circuit as follows:

$$\phi = \frac{F}{R} \text{ or maxwells} = \frac{\text{gilberts}}{\text{oersteds}}$$

This relationship serves to define the oersted.

4. MAGNETIZING FORCE

The intensity of the magnetizing influence in any given part of a magnetic circuit is called the magnetizing force (H). The magnetizing force thus defined is of the nature of a potential gradient. The cgs unit of magnetizing force is the gilbert per centimeter. At the center of a very long uniformly wound solenoid having n turns per centimeter and carrying a current of I amperes, the magnetizing force is

$$H = 0.4 \pi n I$$

5. MAGNETIC INDUCTION

Magnetic induction (B) is the density of the magnetic flux across a section normal to the direction of the flux. Across any section in which the flux is uniformly distributed, the magnetic induction in cgs units is

$$B = \frac{\phi}{S}$$

where S is the area of the section in square centimeters. The cgs unit of magnetic induction is called the gauss, and is defined from this relation.

6. MAGNETIC PERMEABILITY

The ratio of magnetic induction to the corresponding magnetizing force for any substance is called the magnetic permeability (μ).

$$\mu = \frac{B}{H} \text{ or permeability} = \frac{\text{gausses}}{\text{gilberts per cm}}$$

7. INTENSITY OF MAGNETIZATION

The degree of magnetization of a substance is sometimes expressed as the intensity of magnetization (J). No name has been assigned to the unit for this quantity. Its relation to magnetic induction is indicated by the formula

$$J = \frac{B - H}{4\pi}$$

This unit is mainly used in expressing magnetic conditions of feebly magnetic substances.

8. MAGNETIC SUSCEPTIBILITY

The ratio of the intensity of magnetization to the magnetizing force is called the magnetic susceptibility (κ)

$$\kappa = \frac{J}{H}$$

The magnetic properties of feebly magnetic substances are generally expressed in terms of susceptibility rather than permeability.

III. MAGNETIC CHARACTERISTICS OF MATERIALS

1. CLASSIFICATION OF MATERIALS

Materials are classified with respect to their magnetic properties as either ferromagnetic, paramagnetic, or diamagnetic. Ferromagnetic materials have a magnetic permeability greater than 1 and

very large; paramagnetic materials have a magnetic permeability slightly greater than 1; and diamagnetic materials have a magnetic permeability less than 1. The magnetic susceptibility of diamagnetic substances is negative. Ferromagnetic materials exhibit the phenomenon of magnetic hysteresis, which will be discussed later, and the magnetic permeability is variable, depending upon the degree of magnetization and previous treatment. The susceptibility of paramagnetic and diamagnetic substances is constant and they do not

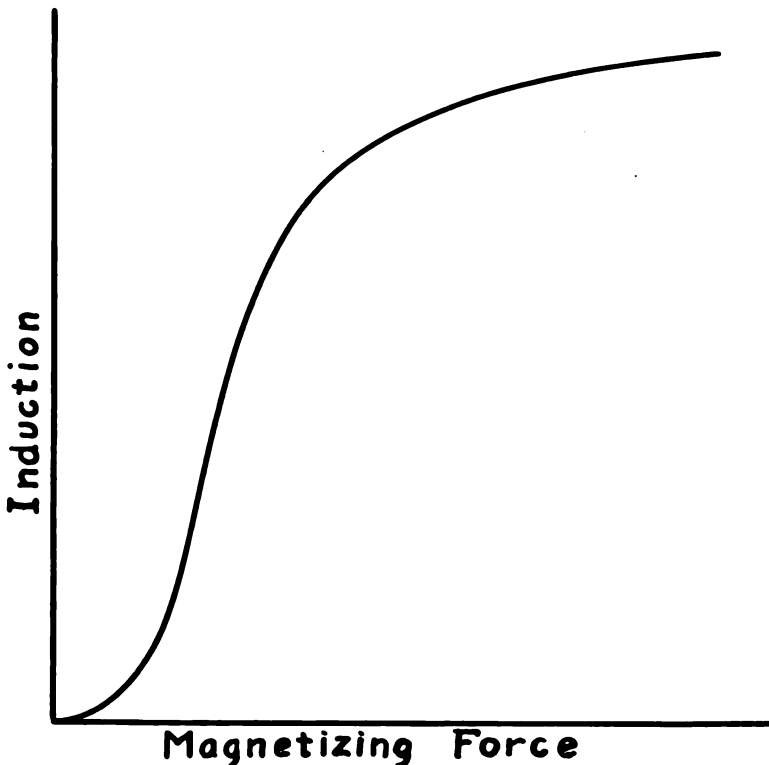


FIG. 1.—*Typical curve of magnetic induction*

have magnetic hysteresis. Ferromagnetic materials are by far the most important from the industrial point of view.

2. INDUCTION

The magnetic properties of ferromagnetic materials are commonly expressed in terms of corresponding values of magnetic induction (B) and magnetizing force (H) or quantities derived from them. A typical magnetization curve is shown in Figure 1. It is to be noted that the induction is not directly proportional to the magnetizing force. In other words, the magnetic permeability does

not have a single value, but depends upon the degree of magnetization. As stated above, this is characteristic of ferromagnetic substances. As the magnetizing force is increased from a zero value, the magnetization proceeds in three more or less distinct stages. In the first stage, the induction increases at a relatively slow rate with increase of magnetizing force. In the second stage, the rate of increase is much greater, while in the third stage the induction increases at a continually decreasing rate. The limits of the three

stages are more or less definite according to the nature of the material.

3. HYSTERESIS

The phenomenon of magnetic hysteresis is illustrated in Figure 2. If the magnetizing force is reduced from some maximum value, the induction does not follow the magnetization curve in reverse order, but decreases in the manner indicated by the curve. When the magnetizing force has been reduced to a zero value, a certain value of induction remains. This is called the residual induction

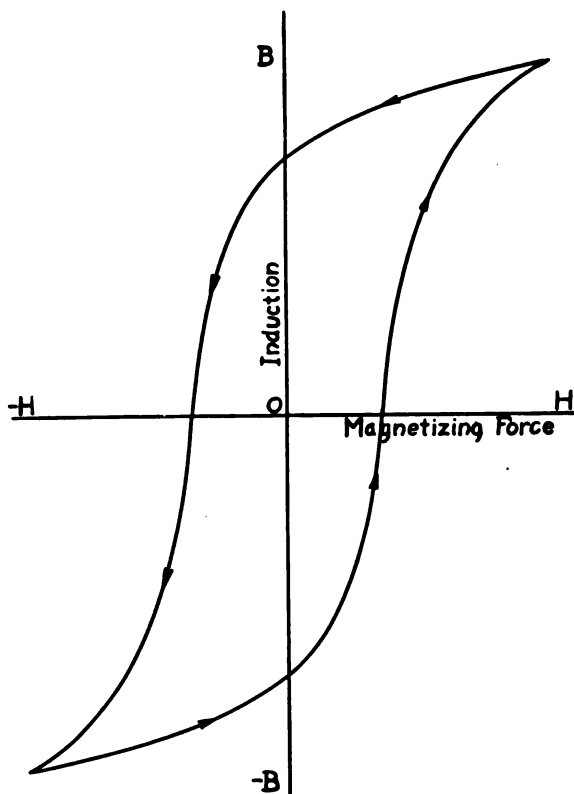


FIG. 2.—Typical magnetic hysteresis loop

(B_r). In order to reduce the induction still further, it is necessary to apply a magnetizing force in the reverse direction. The value of reversed magnetizing force necessary to bring the induction to zero is called the coercive force (H_c). After the magnetizing force has been carried from a certain maximum value in one direction to an equal value in the opposite direction a sufficient number of times, the induction cycle becomes a closed loop, as indicated in the figure. This loop is called a hysteresis loop, and its area is proportional to the energy expended in carrying the material through a complete cycle of magnetization.

4. NORMAL INDUCTION

The induction resulting from the application of a magnetizing force of a given value depends upon the previous magnetic condition of the specimen and upon the mode of approach to the given magnetizing force; that is, the magnetization curve obtained depends upon the initial magnetic condition of the material and the manner in which the test is made. In order to obtain consistent and reproducible results, therefore, it is necessary to follow a definite procedure in making the tests. The effect of previous magnetic history, or magnetic memory as it might be termed, can be removed by demagnetization. This is accomplished by subjecting the specimen to a succession of reversals of magnetizing force gradually decreasing from a certain maximum value to one somewhat lower than the lowest at which a determination is to be made. Experiment has shown (1)¹ that demagnetization should be started from an initial value of magnetizing force well above that corresponding to maximum permeability, but not necessarily from a magnetizing force higher than any previously experienced by the specimen. After demagnetization, points on the induction curve are obtained by observing the induction resulting from the application of a given magnetizing force after a sufficient number of reversals to bring the material to a cyclic condition, thus closing up the hysteresis loop. After a determination has been made, further measurements can be made at higher values of magnetizing force without demagnetizing again, but if a lower point is desired, the demagnetization process must be repeated. Values of induction obtained in this manner are called "normal induction" and are reproducible for a given specimen within the limits of experimental error. The normal induction curve is the locus of the tips of a succession of hysteresis loops as illustrated in Figure 3.

5. NORMAL HYSTERESIS

When points on a normal hysteresis loop are to be determined, cyclic condition is first obtained by a number of reversals of the magnetizing force corresponding to the desired tip, and the induction is noted when the magnetizing force is reduced to some lower value either in the same or opposite direction. Before each determination the material is brought back to a cyclic condition by reversals of the maximum magnetizing force. This procedure differs somewhat from the "step-by-step" method, but has the advantage of giving more consistent and reliable results.

¹ The numbers in parentheses here and throughout the text refer to the references contained in the last section of the circular.

6. CORE LOSS

When materials are subjected to alternating magnetic fields, as in the cores of transformers, a certain amount of energy is expended which can not be recovered but is dissipated in the form of heat. This loss of energy is called core loss. Core loss is made up of two components, hysteresis and eddy currents. The hysteresis loss depends upon the area of the hysteresis loop of the material and the frequency of alternations. The eddy currents are induced in the core by the varying magnetic flux and depend not only upon the

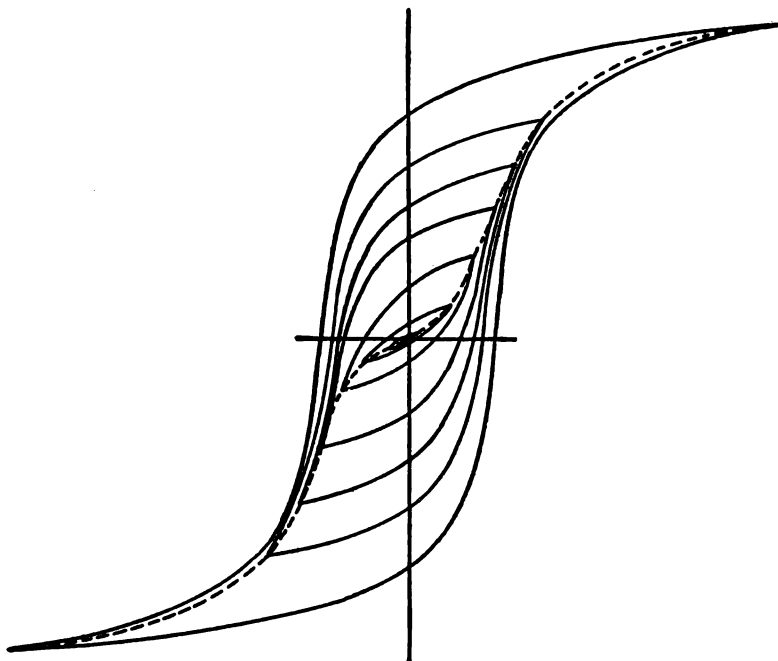


FIG. 3.—Showing that the curve of normal induction is the locus of the tips of a family of hysteresis loops

frequency and maximum induction but also upon the electrical resistivity of the material, the thickness of the laminations, and the insulation between them.

IV. METHODS OF MEASUREMENT

1. NORMAL INDUCTION AND HYSTERESIS

There are several different methods by which measurements of normal induction and hysteresis are ordinarily made. These methods may be classified in terms of the manner in which the magnetic

induction is determined as (a) magnetometric, (b) traction, (c) air gap, and (d) ballistic.

In the magnetometric method the induction is measured in terms of the deflection of a suspended magnetic needle placed in a definite position with respect to the test sample. This method is especially suitable for observing slow changes in induction such, for instance, as occur when a specimen is heated or cooled. It has been described by Ewing (2) and by Gray and Ross (3) who used the method for determining the thermomagnetic properties of various materials. The magnetometer is a very delicate instrument and is sensitive to variations in the earth's magnetic field. It is not, therefore, to be recommended for general magnetic testing.

In the traction methods the induction is estimated in terms of the mechanical force of attraction between the surfaces of two magnetized bodies, one of which is the specimen under test. The Du Bois (4) balance is perhaps the best known of this type of permeameter. Traction permeameters require rather careful machining of the specimens and do not yield results of high accuracy. They are not in general use in the United States.

In the air-gap method the magnetic circuit is closed, except for a transverse air gap in which some measuring device, such as a deflecting coil, a rotating armature, or a bismuth spiral, is located. Perhaps the best known of this type of instrument is the Koepsel permeameter (5). This apparatus is very simple and convenient to operate, but is subject to rather large and uncertain errors, depending upon the type of materials under test.

The ballistic method is so called because it employs a ballistic galvanometer (or fluxmeter) for the determination of the value of magnetic induction. The ballistic method is used for the greater part of the magnetic testing done at the Bureau of Standards.

The ballistic method is applied in the following forms: (a) The Rowland ring, (b) the Burrows permeameter, (c) the straight solenoid, (d) the Fahy Simplex permeameter, (e) the magnetic comparator, and (f) a modification of the isthmus method.

(a) **THE ROWLAND RING.**—The magnetic circuit used in this method consists of an annular ring cut from the material to be tested. A diagram of connections is given in Figure 4. The magnetizing winding is uniformly distributed around the ring and the magnetizing force is calculated from the formula:

$$H = \frac{0.4 \pi NI}{L}$$

in which

N = total number of turns,

I = current in amperes,

L = mean circumference of the ring in cm.

On account of the difference in concentration of the winding over the inner and outer part of the ring, the magnetizing force varies over the cross section causing an error in the result which depends upon the ratio of the mean diameter to the radial width of the ring (6). If this ratio is greater than 10, however, the error can usually be neglected.

The magnetic induction is determined in terms of the deflection of a ballistic galvanometer connected to a suitable test coil wound on the specimen, preferably under the magnetizing winding. Whenever there is a change in the flux linked with this test coil, an electromotive force is induced, and a certain quantity of electricity flows in the galvanometer circuit. The quantity of electricity is proportional to the change in flux. If the flux is reversed in direction by reversing the magnetizing current, the galvanometer deflection will be proportional to twice the flux.

The galvanometer is calibrated by means of a standard mutual inductance, the secondary of which is permanently connected in

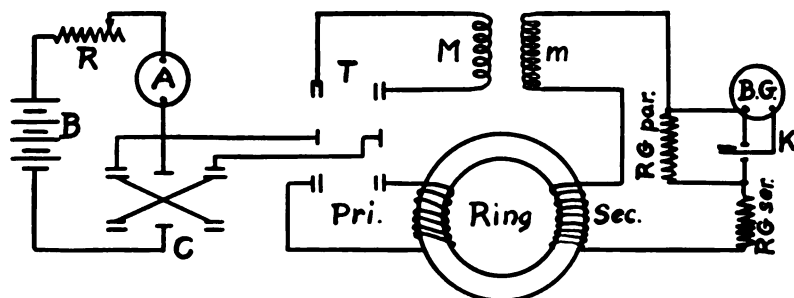


FIG. 4.—Connections for the ring method

series with the test coil. It is usually convenient to adjust the sensitivity of the galvanometer by means of suitable series and parallel resistances so that the scale is direct reading in terms of magnetic induction. It is customary to make 1 cm deflection correspond to the reversal of an induction of 1,000 gauss. The calibrating current to be reversed in the primary of the mutual inductance depends upon the value of the mutual inductance, the number of turns in the test coil, and the cross section of the specimen, and is calculated from the following formula:

$$I_c = \frac{BAN}{M \times 10^8}$$

in which

- I_c = calibrating current in amperes,
- B = induction in gauss.
- A = cross-sectional area in cm^2 ,
- N = number of turns in the test coil,
- M = mutual inductance in henrys.

It is often convenient to use 100 turns in the test coil and to adjust the sensitivity of the galvanometer so as to have a deflection of 10 cm for a reversal of 10,000 gauss. When points on the hysteresis loop are to be determined, an auxiliary series resistance is suddenly inserted in the magnetizing circuit. In this case, care must be taken to remember that, since the galvanometer is calibrated for reversal of the induction, the readings must be multiplied by 2.

(b) **THE BURROWS PERMEAMETER.**—It is generally more convenient to prepare samples in the form of straight bars of moderate length and uniform cross section than to prepare ring specimens. There are a number of testing methods adapted to samples of this form, but the most accurate one for samples of uniform permeability along their length and having a maximum permeability, not exceeding 5,000, is the compensated double yoke method of Burrows (7). In this method auxiliary compensating coils are used to provide the extra magnetomotive force required for the yoke and joints in the

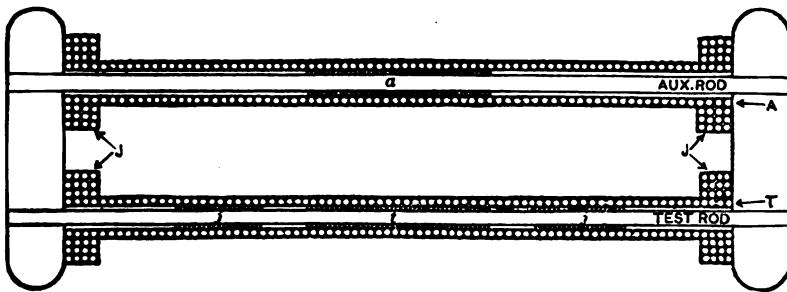


FIG. 5.—Magnetic circuit of the Burrows permeameter showing the relative positions of the magnetizing and test coils

magnetic circuit, and the current in them is adjusted so as to produce a uniform induction in the bar under test.

Figure 5 shows the magnetic circuit of the Burrows permeameter and the relative positions of the magnetizing and test coils. The test rod and its auxiliary, which should be of the same size and material, are joined at the ends by soft-iron yokes which make good magnetic joints and complete the magnetic circuit. The magnetizing coils *T* and *A* are located over the test rod and auxiliary, respectively. Coil *J* is in four sections, connected in series, and located over the ends of the rods as near to the joints as possible. In operation, the currents in these three windings are so adjusted before each reading that there is equal flux in the two rods, and no leakage from the greater part of the test rod. When this condition is realized the value of the applied magnetizing force can be calculated from the current and number of turns per centimeter in the solenoid surrounding the test rod. For testing the compen-

sation and determining the value of the induction when the compensation is properly adjusted there are three test coils designated as t , a , and j , respectively. These coils are each of the same number of turns and are distributed as shown in the figure; t is wound over the middle of the test bar, a over the middle of the auxiliary bar, and j is wound half over one end and half over the other end of the test bar far enough away from the yokes and joints to avoid disturbances from these causes. When, upon reversal of the current in the magnetizing windings, there is no residual deflection in the ballistic galvanometer whether connected to t and a or to

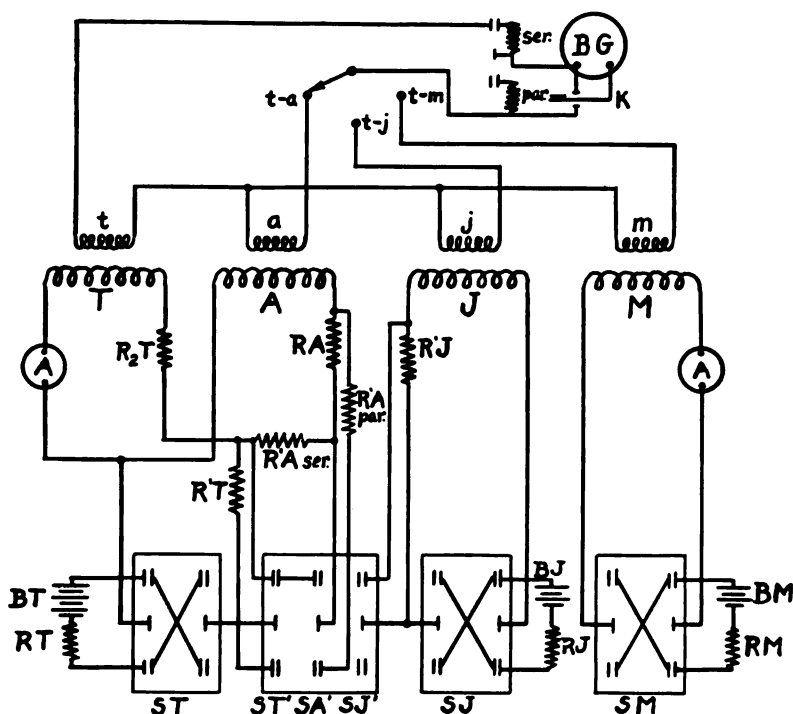


FIG. 6.—Connections for the Burrows permeameter

t and j in series opposition, the magnetizing currents are properly adjusted. Under these conditions the induction is measured in terms of the deflection of the ballistic galvanometer connected to t alone, and the magnetizing force is proportional to the current in the winding T . As usually constructed, the magnetizing coil is so wound that the magnetizing force is 100 times the current in amperes. A diagram of connections is given in Figure 6. The switches ST' , SA' , and SJ' are for the purpose of inserting resistances in the corresponding circuits during the determination of points on the hysteresis loop. ST' should make contact on the forward point

before breaking at the other. The calibration of the ballistic galvanometer is carried out as indicated for the ring method.

A correction must be made to the observed value of induction. This correction, which is necessary because of the flux in the space between the specimen and the test coil, must be applied for all ballistic methods. The amount to be subtracted from the observed value of induction is proportional to the magnetizing force and depends

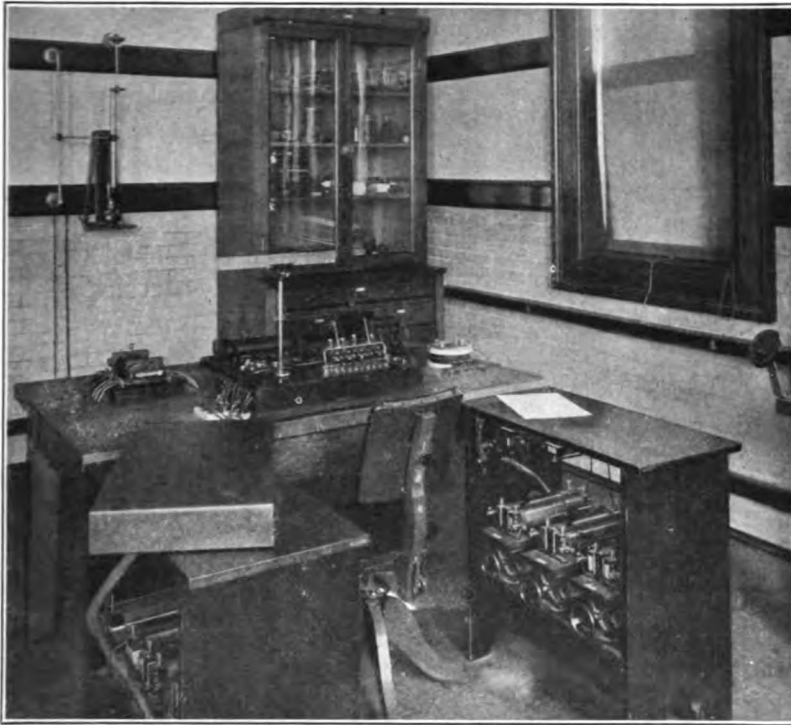


FIG. 7.—Burrows permeameter and accessory apparatus

upon the relative areas of the test coil and specimen. It is equal to kH where

$$k = \frac{a - \lambda}{A}$$

a = area of test coil,

A = area of specimen.

Figure 7 shows the complete set-up for the Burrows permeameter. The Burrows permeameter is an absolute instrument in that its constants can be derived from measurements of its dimensions, and therefore is suitable for standardization work under proper conditions. It is, however, extremely sensitive to the influence of variations in permeability along the length of the specimen, and the

results obtained on inhomogeneous materials should be interpreted with this fact in mind.

(c) **THE STRAIGHT SOLENOID.**—Sometimes it is more convenient to make measurements on a single straight bar than to prepare a ring or use the Burrows permeameter. It is difficult to obtain accurate results with this method because the magnetization of the specimen is not uniform and the free poles give rise to a self-demagnetizing effect. Uniform magnetization can be obtained by making the sample in the form of an ellipsoid of revolution, for which also the demagnetizing coefficient can be calculated. This form of specimen is not often used, however, and the demagnetizing effect for straight cylinders must be experimentally determined. The amount to be deducted from the value of the applied magnetizing force depends upon the ratio of length to diameter of the specimen and the intensity of magnetization. It has also been found that the demagnetizing coefficient is influenced by the absolute dimensions of the sample as well. The safest way is to determine the coefficient for a specimen of the same dimensions as the test sample and of approximately the same magnetic quality, although values are given in the Smithsonian Physical Tables and other tables of physical constants.

If the ratio of length to diameter is very large (200 or more), the demagnetizing effect of the ends can generally be neglected.

The procedure for making the test with a straight solenoid is substantially the same as for the ring test previously described. The correction for air flux is made as in the Burrows method.

(d) **THE FAHY SIMPLEX PERMEAMETER.**—This permeameter (fig. 8) operates on a somewhat different principle (8) than the Burrows permeameter and requires but a single specimen. The magnetizing force is applied by means of an electromagnet, across the poles of which the specimen is clamped. A uniformly wound test coil extends over the whole length of the specimen. A ballistic galvanometer connected to this test coil indicates the induction in the specimen when the magnetizing current is reversed.

The magnetizing force is measured by means of a test coil uniformly wound on a nonmagnetic form and extending between two iron blocks which are clamped to the ends of the specimen. The deflection of a ballistic galvanometer connected to such a coil when the magnetizing force is changed in value is proportional to the change in magnetic potential between the ends of the coil. The function of the iron blocks is in effect to transfer the ends of the test coil to the ends of the specimen. When the magnetic circuit is properly constructed of suitable materials, this method is capable of giving very satisfactory results. It does not require an auxiliary specimen and no compensation is necessary. It is also less sensitive than the Bur-

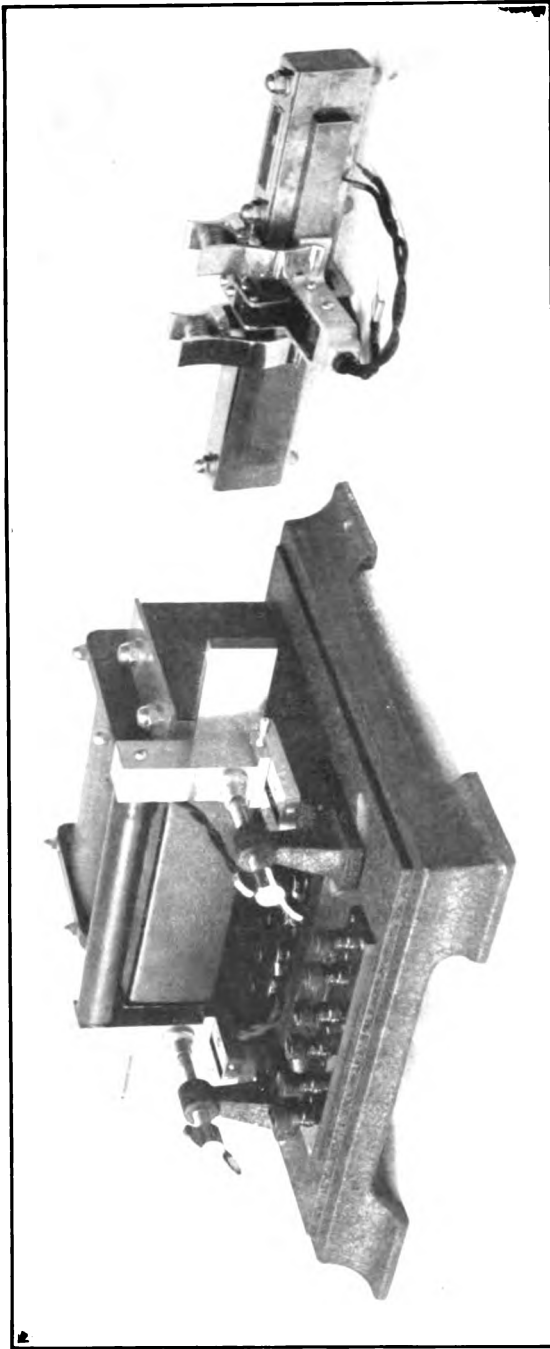


FIG. 8.—*Simplex permeameter and the high magnetization adapter*

rows permeameter to the effect of magnetic inhomogeneity along the length of the specimen. The galvanometer is calibrated by means of a standard mutual inductance as in the methods previously described

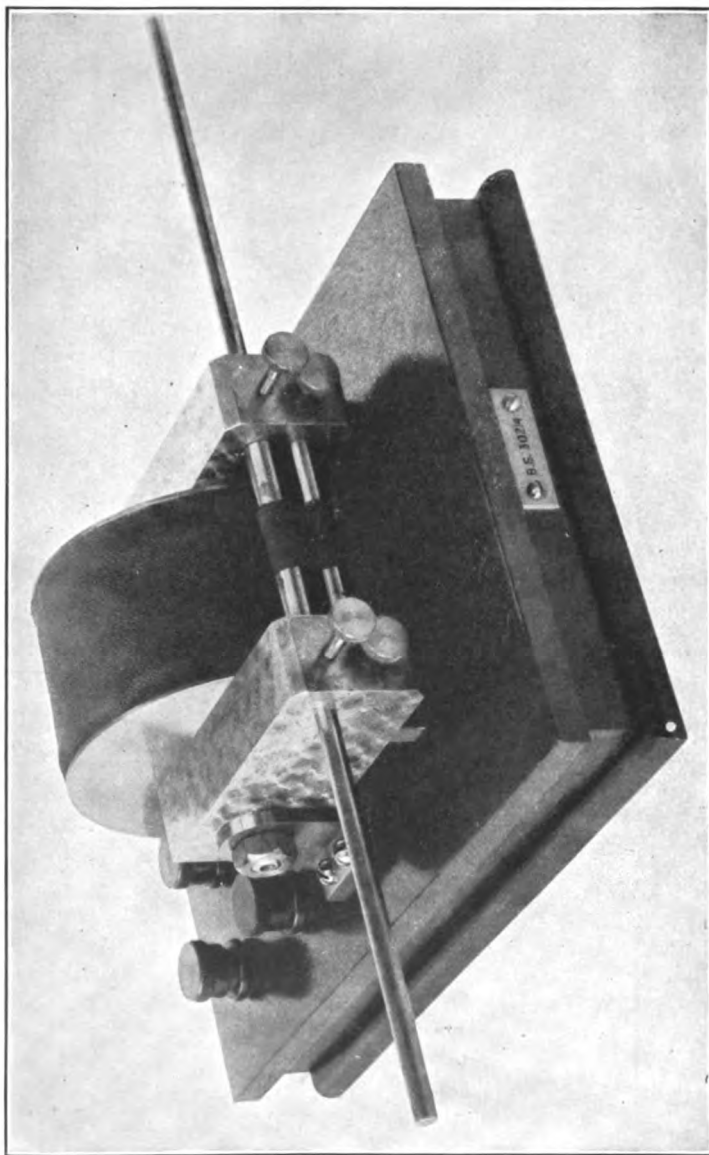


FIG. 9.—Magnetic comparator

and the usual correction for air flux linked with the test coil but not in the specimen is applied.

By the use of an adapter for high magnetization, also shown in the photograph, the range of this permeameter may be extended up to magnetizing forces of 1,000 gilberts per centimeter or more,

according to conditions. By means of the adapter the effective length of the specimen is shortened and a special test coil with iron end pieces is clamped on to the sample for the determination of the magnetizing force. The principle and procedure are the same as for the regular method.

(e) **THE MAGNETIC COMPARATOR.**—It sometimes happens that measurements are to be made on materials of which only a small quantity is available. The ordinary methods of direct measurement are not satisfactory for this purpose. A magnetic comparator, shown in Figure 9, has been devised for measurements on small samples (9). It consists of an electromagnet having holes 6 mm in diameter so located in its pole pieces that the sample under test and a reference bar can be clamped so as to be parallel to each other and about 12 mm apart. Test coils mounted on brass forms encircle each bar. With this arrangement, if there were no magnetic leakage, an equal magnetomotive force would be impressed on each bar. As a matter of fact, however, there is magnetic leakage and the magnetizing forces are not exactly equal on the two bars. In order to take this inequality into account, the apparatus is calibrated by using a standard having properties as near as possible like those of the sample to be tested. Corresponding values of induction in the reference bar and the standard, together with the magnetization curve for the standard, furnish the data for determining the magnetizing force in terms of the induction in the reference bar. The test specimen is then inserted in place of the standard and another set of corresponding values of induction observed. From these values, together with the previous calibration of the reference bar, the normal induction curve for the test specimen can be obtained. The accuracy obtainable with this method depends primarily upon the degree of similarity between the specimen and the standard used for calibration. This apparatus has proven to be very satisfactory, especially in testing pure alloys and other materials of which only small quantities could readily be prepared. Measurements have been made up to 500 gilberts per centimeter with this method with good results.

(f) **THE MODIFIED ISTHMUS METHOD.**—None of the methods described above, with the possible exception of the Fahy Simplex permeameter using the high-magnetization adapter, are suitable for measurements with very intense magnetizing fields, the range being limited by the heating of the magnetizing coils. For measurements above 100 gilberts per centimeter, a modification of the classical isthmus method of Ewing (2) has been developed (10). (Fig. 10.) The sample used in this method consists of a cylindrical bar 6 mm in diameter and at least 5 cm long.

The poles of an electromagnet of the Du Bois type are pierced coaxially so that the sample can be extended through them. The

gap between the pole pieces is 2 cm long. Surrounding the specimen are two coaxial and coextensive test coils each having the same number of turns. The inner coil is of as small a diameter as possible (about 7 mm) while the outer coil has a diameter of approximately 12.5 mm.

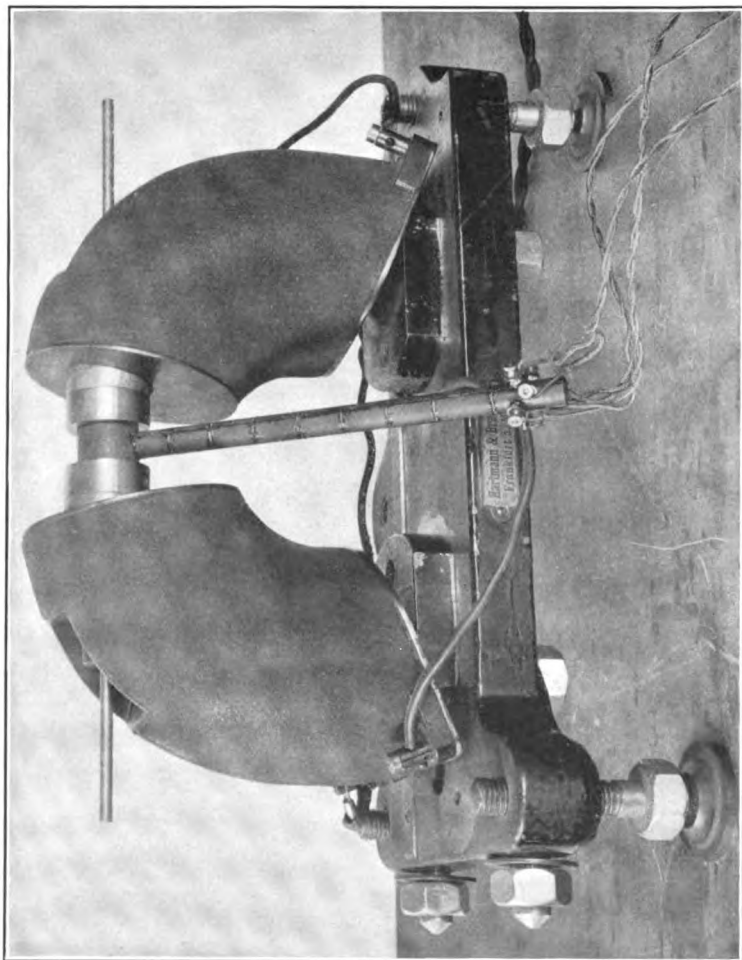


FIG. 10.—Apparatus for testing with intense fields

Normal induction measurements are made upon reversal of the magnetizing current. When the galvanometer is connected to the inner coil alone, the deflection on reversal is proportional to the induction in the specimen. When the galvanometer is connected to the two coils in series opposition, the deflection upon reversal is proportional to the magnetizing force. The length of the gap and the diameter of the outer test coil are so proportioned that the magnetizing field is uniform throughout the area between the two test coils.

Special switching arrangements (11) permit of the determination of points on the hysteresis loop. With this apparatus, measurements can be made in the range of magnetizing force from 100 to approximately 3,000 gilberts per centimeter.

2. CORE LOSS

For the measurement of core loss two methods are used—the Epstein method as specified by the American Society for Testing Materials and the Lloyd method developed at the bureau. The core loss apparatus used at the bureau is shown in Figure 11.

(a) THE A. S. T. M. METHOD.—This method is the most commonly used one, especially for routine acceptance tests. It requires 10 kg (22 pounds) of material cut into strips 50 cm (19½ inches) long and 3 cm (1¼ inches) wide. In order to take account of the difference in loss according to the direction of magnetization, half of the strips are cut parallel and half at right angles to the direction of rolling. The strips are made up into four equal bundles and inserted in four solenoids so as to form a square with butt joints. The bundles are so arranged that opposite sides of the square consist of material cut in the same manner. The strips are held in place at the corners by suitable clamps.

The solenoids have two windings, primary and secondary. An electromotive force of approximately sinusoidal wave form is applied to the primary winding and a voltmeter and the potential coil of a wattmeter are connected to the secondary winding. The wattmeter should be especially designed for low-power factors. The impressed voltage is adjusted, preferably by means of a suitable autotransformer, until the voltage of the secondary is that given by the equation:

$$E = \frac{4fNnBM}{4D10^8}$$

in which

- f = form factor of primary emf = 1.11 for sine wave,
- N = number of secondary turns,
- n = frequency in cycles per second,
- B = maximum induction in gaussses,
- M = total mass in grams,
- l = length of strips in centimeters,
- D = specific gravity.

In the standard test the frequency is 60 cycles per second, the maximum induction is 10,000 gaussses, the mass is 10,000 grams, and the length of strips is 50 cm. The specific gravity is either measured or assumed. It is customary to assume a specific gravity of 7.5 for high-resistance steel and 7.7 for low-resistance steel.

When the voltage and frequency have been properly adjusted, the wattmeter gives the power consumed in the steel and the secondary circuit. The loss in the secondary circuit can be calculated in terms

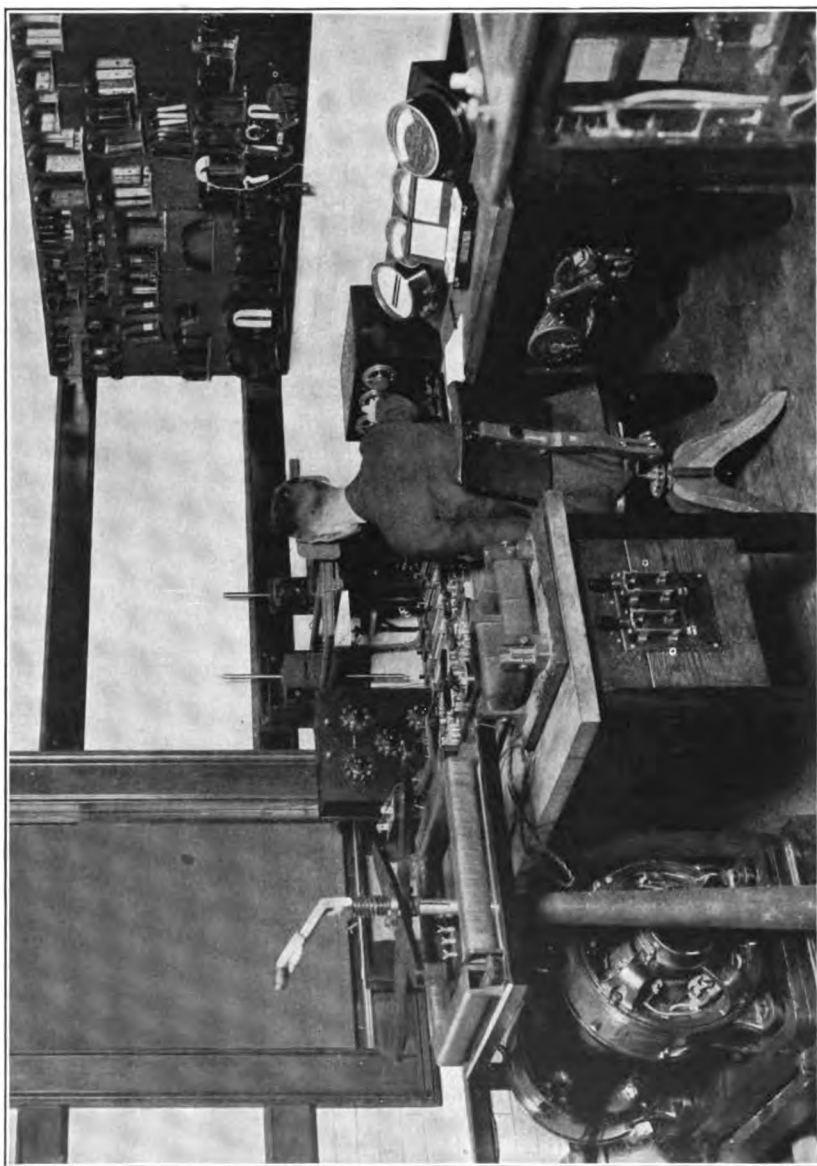


FIG. 11.—Apparatus for core loss testing

of the voltage and resistance. Subtracting this correction from the total power gives the net power consumed in the steel as hysteresis and eddy-current loss. Dividing this value by 10 gives the core loss in watts per kilogram.

When tests are made under other than the standard conditions, especially if the maximum induction is carried much above 10,000 gauss. the possibility of distortion of the wave form must be taken into consideration as well as additional uncertainties from other sources.

(b) **THE LLOYD METHOD.**—Errors in the A. S. T. M. method are largely due to nonuniformity of flux distribution which results from the relatively poor magnetic joints at the corners. The Lloyd method is designed (13) to overcome this difficulty, in so far as possible, by improving the joints. Strips are cut 25.4 cm (10 inches) long and 5.1 cm (2 inches) wide and formed into a square with the strips placed on edge. Ten or twelve strips are used for each side of the square, according to the thickness of the material. The joints are improved by the insertion of right-angled corner pieces of the same or similar material. The corners are then secured with special clamps so designed as to avoid eddy currents in the clamps.

With this form of magnetic circuit, which takes from 1.5 kg (3.3 pounds) to 2 kg (4.4 pounds), the flux distribution is greatly improved, so that it is possible to make satisfactory separations of hysteresis and eddy-current losses by testing at two frequencies.

The Lloyd test is not used to any extent for general testing on account of the extra complication incident to the use of the corner pieces for which corrections must be made and the necessity for rather sensitive instruments, but is very valuable in special cases where rather complete and detailed data are required for a particular sample of material, or where data are required at higher values of maximum induction than 10,000 gauss. It is possible, for instance, to carry the induction up to about 14,000 gauss before serious wave distortion is produced.

3. SUSCEPTIBILITY

Measurements of the susceptibility of feebly magnetic substances are made chiefly to determine whether or not the materials are suitable for use in the construction of instruments and various other apparatus in which the use of magnetic materials is objectionable.

For measurements of extreme precision the Curie balance (14) or some modification thereof is necessary, but for most purposes a ballistic method, which, although less sensitive, is much more convenient to operate and is entirely adequate. In the ballistic test a straight solenoid is used having a test coil of several hundred turns mounted within it, and in which the specimen can be inserted. On account of the very low value of magnetization in the specimen, the self-demagnetizing effect is so small that it can be neglected. A variable mutual inductance is used, with its primary connected

in series with the magnetizing solenoid and its secondary in series opposition with the test coil. This mutual inductance is so adjusted as to balance the mutual inductance between the solenoid and test coil. This adjustment is made with no specimen in the test coil, so that there is no deflection of the ballistic galvanometer when the primary current is reversed. The galvanometer can then be used at its maximum sensitivity. When a specimen is inserted within the test coil and the magnetizing current is reversed, the deflection of the galvanometer is proportional to the intensity of magnetization of the specimen. The magnetizing force is calculated from the current and the constants of the solenoid in the usual way, and the susceptibility is the ratio of the intensity of magnetization to the magnetizing force.

The galvanometer can be calibrated by means of the variable mutual inductance used for compensating for the test coil by reversing a known current in its primary or, preferably, by a second fixed standard of mutual inductance whose secondary is permanently connected in the galvanometer circuit.

V. MAGNETIC STANDARDS

It is not possible to realize any of the units of magnetic quantity in concrete form. Carefully selected and prepared test specimens whose magnetic properties have been accurately determined are suitable for use in the intercomparison and standardization of permeameters, however, and it may be proper, therefore, to refer to such test specimens as magnetic standards.

1. LIMITS OF ACCURACY

The problem of magnetic testing consists in determining simultaneous values of magnetic induction and magnetizing force. It is relatively easy to obtain fairly accurate values of induction, but the accurate determination of the corresponding magnetizing force is not so easy. As a matter of fact, it is only by the exercise of great care in the selection of test specimens and manipulation of the testing apparatus that an accuracy of 1 per cent can be attained. The influence of the quality and condition of the test specimen is of great importance, especially in the standardization of permeameters because inaccuracies really arising from the condition of the specimen itself should not be charged to the testing apparatus.

2. REQUIREMENTS OF STANDARD SPECIMENS

Specimens to be used as standards for the calibration of permeameters should be chosen and prepared with the following points in

view: (a) Magnetic uniformity along the length, (b) metallurgical stability, and (c) uniformity of section.

If the specimen varies in permeability along its length, errors are introduced in the measurements which can not be calculated or eliminated by compensation, and which may be of considerable magnitude. It is not at all out of the question to have errors due to this cause alone which amount to 25 per cent or more. Moreover, various methods are sensitive to this influence in varying degrees. It is obvious, therefore, that such specimens should not be used for the intercomparison or standardizing of testing apparatus. Various methods for the determination of the degree of uniformity of magnetic test specimens have been proposed (15), but probably the most satisfactory one is to prepare a specimen much longer than is required for the final form and to make measurements at suitable intervals along its length. If the results of these measurements are in agreement, then the specimen is, from this point of view, satisfactory to use as a standard.

It is well known that specimens of steel freshly heat treated are not metallurgically stable; that is, changes in internal structure or condition may go on for some time. These changes are accompanied by corresponding changes in magnetic properties. It is necessary, therefore, to make sure that specimens to be used as magnetic standards are metallurgically stable. This can be accomplished by either natural or artificial aging. It is also desirable to repeat measurements at intervals in order to be assured that the magnetic properties are not changing.

It is quite obvious that irregularity in cross section along the length of a specimen would have an effect similar to that of a variation in magnetic permeability. For this reason it is important that care should be used in preparing the specimen to maintain a uniform cross section.

3. GENERAL PRECAUTIONS

In the calibration and use of magnetic standards it is necessary to avoid (a) mechanical strain, (b) variations in temperature, and (c) mechanical vibration.

Mechanical strain influences the magnetic properties of materials to a marked degree. It is important, therefore, in the calibration and use of magnetic standards that they be clamped so as to be free from strain. The effect of strain is particularly noticeable in high-permeability materials and in the lower part of the magnetization curve (16).

The effect of variations in temperature is not negligible (17), and care should be taken that standards be not heated during the course of a test. The temperature coefficient is not constant (18)

and varies for different materials or even for the same material with different heat treatments.

Mechanical vibration should be avoided in magnetic testing. It has a tendency to increase the apparent permeability and to decrease the hysteresis. This is not generally a serious factor, but for work of high accuracy it should be considered and the specimens protected if necessary from excessive vibration.

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WASHINGTON, July 12, 1926.



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DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 18

STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL

[2d Edition]

Issued July 1, 1911



WASHINGTON
GOVERNMENT PRINTING OFFICE

1911

STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL.

For the information of those concerned the provisions of an act of Congress approved March 3, 1893 (27 Stat. L., 746), establishing a uniform standard for sheet and plate iron and steel in the United States, are reprinted.

A variation of $2\frac{1}{2}$ per cent either way is permitted, so that the excessive number of decimal places in the "approximate" equivalents is undue refinement for the practical purposes for which the act was established. Moreover, the values in some cases are beyond the limits of measurement of the highest precision. For these reasons and greater convenience in use, the figures not usually required in view of the tolerance are printed in smaller type.

S. W. STRATTON,
Director.

(2)

AN ACT ESTABLISHING A STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the purpose of securing uniformity, the following is established as the only standard gage for sheet and plate iron and steel in the United States of America, namely:

Number of gage	Approximate thickness in fractions of an inch	Approximate thickness in decimal parts of an inch	Approximate thickness in millimeters	Weight per square foot in ounces avoirdupois	Weight per square foot in pounds avoirdupois	Weight per square foot in kilograms	Weight per square meter in kilograms	Weight per square meter in pounds avoirdupois
0000000	1-2	.5	12.7	320	20.00	9.072	97.65	215.28
000000	15-32	.46875	11.90625	300	18.75	8.505	91.55	201.82
00000	7-16	.4375	11.1125	280	17.50	7.983	85.44	188.37
0000	13-32	.40625	10.31875	260	16.25	7.371	79.33	174.91
000	3-8	.375	9.525	240	15	6.804	73.24	161.46
00	11-32	.34375	8.73125	220	13.75	6.237	67.13	148.00
0	5-16	.3125	7.9375	200	12.50	5.67	61.03	134.55
1	9-32	.28125	7.14375	180	11.25	5.103	54.93	121.09
2	17-64	.265625	6.746875	170	10.625	4.819	51.88	114.37
3	1-4	.25	6.35	160	10	4.536	48.82	107.64
4	15-64	.234375	5.953125	150	9.375	4.252	45.77	100.91
5	7-32	.21875	5.55625	140	8.75	3.969	42.72	94.18
6	13-64	.203125	5.159375	130	8.125	3.685	39.67	87.45
7	3-16	.1875	4.7625	120	7.5	3.402	36.62	80.72
8	11-64	.171875	4.365625	110	6.875	3.118	33.57	74.00
9	5-32	.15625	3.96875	100	6.25	2.835	30.52	67.27
10	9-64	.140625	3.571875	90	5.625	2.552	27.46	60.55
11	1-8	.125	3.175	80	5	2.268	24.41	53.82
12	7-64	.109375	2.778125	70	4.375	1.984	21.36	47.09
13	3-32	.09375	2.38125	60	3.75	1.701	18.31	40.36
14	5-64	.078125	1.984375	50	3.125	1.417	15.26	33.64
15	9-128	.0703125	1.7859375	45	2.8125	1.276	13.73	30.27
16	1-16	.0625	1.5875	40	2.5	1.134	12.21	26.91
17	9-160	.05625	1.42875	36	2.25	1.021	10.99	24.22
18	1-20	.05	1.27	32	2	.9072	9.765	21.53

Number of gage	Approximate thickness in fractions of an inch	Approximate thickness in decimal parts of an inch	Approximate thickness in millimeters	Weight per square foot in ounces avoirdu- pois	Weight per square foot in pounds avoirdu- pois	Weight per square foot in kilograms	Weight per square meter in kilograms	Weight per square meter in pounds avoirdu- pois
19	7-160	.04375	1.11125	28	1.75	.7988	8.544	18.84
20	3-80	.0375	.9525	24	1.50	.6804	7.324	16.15
21	11-320	.034375	.873125	22	1.375	.6237	6.713	14.80
22	1-32	.03125	.793750	20	1.25	.567	6.103	13.46
23	9-320	.028125	.714375	18	1.125	.5103	5.493	12.11
24	1-40	.025	.635	16	1	.4536	4.882	10.76
25	7-320	.021875	.555625	14	.875	.3969	4.272	9.42
26	3-160	.01875	.47625	12	.75	.3402	3.662	8.07
27	11-640	.0171875	.4365625	11	.6875	.3119	3.357	7.40
28	1-64	.015625	.396875	10	.625	.2835	3.052	6.73
29	9-640	.0140625	.3571875	9	.5625	.2551	2.746	6.05
30	1-80	.0125	.3175	8	.5	.2268	2.441	5.38
31	7-640	.0109375	.2778125	7	.4375	.1984	2.136	4.71
32	13-1280	.01015625	.25796875	6½	.40625	.1843	1.983	4.37
33	3-320	.009375	.238125	6	.375	.1701	1.831	4.04
34	11-1280	.00859375	.21828125	5½	.34375	.1559	1.678	3.70
35	5-640	.0078125	.1984375	5	.3125	.1417	1.526	3.36
36	9-1280	.00703125	.17859375	4½	.28125	.1276	1.373	3.03
37	17-2560	.006640625	.168671875	4¼	.265625	.1205	1.297	2.87
38	1-160	.00625	.15875	4	.25	.1134	1.221	2.69

And on and after July first, eighteen hundred and ninety-three, the same and no other shall be used in determining duties and taxes levied by the United States of America on sheet and plate iron and steel. But this act shall not be construed to increase duties upon any articles which may be imported.

SEC. 2. That the Secretary of the Treasury is authorized and required to prepare suitable standards in accordance herewith.

SEC. 3. That in the practical use and application of the standard gage hereby established a variation of two and one-half per cent either way may be allowed.

Approved, March 3, 1893.

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U.S. DEPARTMENT OF COMMERCE AND LABOR

GENERAL INVESTIGATION
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CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 19

STANDARD DENSITY AND VOLUMETRIC TABLES

[2d Edition]

Issued September 15, 1911



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1911

DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 19

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Issued September 15, 1911



WASHINGTON
GOVERNMENT PRINTING OFFICE

1911

STANDARD DENSITY AND VOLUMETRIC TABLES

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INTRODUCTION

The wide application of hydrometers as measuring instruments in the collection of revenues in commerce and in the industries makes it very important to define the various scales of indication of these instruments in terms of fundamental units.

The confusion and discordance heretofore resulting from the use of various insufficiently defined hydrometer scales, and the lack of opportunity for verifying standards on a uniform basis, led the Bureau to investigate the problems connected with hydrometry and to prepare standard density tables for definition of hydrometer scales.

In Bureau Circular No. 16 the conditions are announced under which the testing of hydrometers will be conducted, and specifications are given as to the construction, standardization, and accuracy required for hydrometers in order that they be approved as precision instruments.

The present circular comprises the density tables which have been adopted for definition of hydrometer scales, auxiliary tables which have been prepared for reduction of hydrometer readings, tables for computation of volumetric capacity, and others of similar nature giving physical constants for which the Bureau receives frequent inquiries.

In all tables found in this circular the term DENSITY is used to represent the MASS per UNIT VOLUME and is expressed in GRAMS per MILLILITER; that is, all densities are referred to water at 4° C as unity.

The term SPECIFIC GRAVITY is used to express the RELATIVE MASSES of EQUAL VOLUMES of the liquid in question and of water, EACH LIQUID being at a DEFINITELY STATED TEMPERATURE. For example, specific gravity at $\frac{60^{\circ}}{60^{\circ}}$ F means the specific gravity of the liquid at 60° F referred to water at 60° F as unity.

For the sake of uniformity the same abbreviation, D, with the proper temperature basis, is used for both density and specific gravity.

S. W. STRATTON,
Director.

Approved:
BENJ. S. CABLE,
Acting Secretary.

TABLE 1.—Density of Pure Water Free from Air

[Under standard pressure (76 cm), at every tenth part of a degree of the international hydrogen scale from 0° to 41° C, referred to water at 4° C as unity¹]

De- grees Centi- grade	Tenths of Degrees										Mean Differ- ences
	0	1	2	3	4	5	6	7	8	9	
0	0.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59
1	9267	9315	9363	9408	9452	9494	9534	9573	9610	9645	+ 41
2	9679	9711	9741	9769	9796	9821	9844	9866	9887	9905	+ 24
3	9922	9937	9951	9962	9973	9981	9988	9994	9998	*0000	+ 8
4	1.000 0000	*9999	*9996	*9992	*9986	*9979	*9970	*9960	*9947	*9934	- 8
5	0.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	- 24
6	9682	9650	9617	9582	9545	9507	9468	9427	9385	9341	- 39
7	9296	9249	9201	9151	9100	9048	8994	8938	8881	8823	- 53
8	8764	8703	8641	8577	8512	8445	8377	8308	8237	8165	- 67
9	8091	8017	7940	7863	7784	7704	7622	7539	7455	7369	- 81
10	7282	7194	7105	7014	6921	6826	6729	6632	6533	6432	- 95
11	6331	6228	6124	6020	5913	5805	5696	5586	5474	5362	-108
12	5248	5132	5016	4898	4780	4660	4538	4415	4291	4166	-121
13	4040	3912	3784	3654	3523	3391	3257	3122	2986	2850	-133
14	2712	2572	2431	2289	2147	2003	1858	1711	1564	1416	-145
15	1266	1114	0962	0809	0655	0499	0343	0185	0026	*9865	-156
16	0.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	-168
17	8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	-178
18	6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	-190
19	4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	-200
20	2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	-211
21	0233	0016	*9799	*9580	*9359	*9139	*8917	*8694	*8470	*8245	-221
22	0.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	-232
23	5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	-242
24	3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	-252
25	0770	0513	0255	*9997	*9736	*9476	*9214	*8951	*8688	*8423	-261
26	0.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	-271
27	5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	-280
28	2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	-289
29	0.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	-298
30	6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	-307
31	3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	-315
32	0561	0241	*9920	*9599	*9276	*8954	*8630	*8304	*7979	*7653	-324
33	0.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	-332
34	4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	-340
35	0610	0267	*9922	*9576	*9230	*8883	*8534	*8186	*7837	*7486	-347
36	0.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	-355
37	3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	-362
38	0.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	-370
39	6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	-377
40	2497	2116	1734	1352	0971	0587	0203	*9818	*9433	*9047	-384
41	0.991 8661										

¹ According to P. Chappuis, Bureau international des Poids et Mesures, Travaux et Mémoires, XIII: 1907.

TABLE 2.—Density² (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water^{2a}

Per cent alcohol by weight	Temperature						
	10° C	15° C	20° C	25° C	30° C	35° C	40° C
0	0.99973	0.99913	0.99823	0.99708	0.99568	0.99406	0.99225
1	.785	.725	.636	.520	.379	.217	.034
2	.602	.542	.453	.336	.194	.031	.98846
3	.426	.365	.275	.157	.014	.98849	.663
4	.258	.195	.103	.98984	.98839	.672	.485
5	.098	.032	.98938	.817	.670	.501	.311
6	.98946	.98877	.780	.656	.507	.335	.142
7	.801	.729	.627	.500	.347	.172	.97975
8	.660	.584	.478	.346	.189	.009	.808
9	.524	.442	.331	.193	.031	.97846	.641
10	.393	.304	.187	.043	.97875	.685	.475
11	.267	.171	.047	.97897	.723	.527	.312
12	.145	.041	.97910	.753	.573	.371	.150
13	.026	.97914	.775	.611	.424	.216	.96989
14	.97911	.790	.643	.472	.278	.063	.829
15	.800	.669	.514	.334	.133	.96911	.670
16	.692	.552	.387	.199	.96990	.760	.512
17	.583	.433	.259	.062	.844	.607	.352
18	.473	.313	.129	.96923	.697	.452	.189
19	.363	.191	.96997	.782	.547	.294	.023
20	.252	.068	.864	.639	.395	.134	.95856
21	.139	.96944	.729	.495	.242	.95973	.687
22	.024	.818	.592	.348	.087	.809	.516
23	.96907	.689	.453	.199	.95929	.643	.343
24	.787	.558	.312	.048	.769	.476	.168
25	.665	.424	.168	.95895	.607	.306	.94991
26	.539	.287	.020	.738	.442	.133	.810
27	.406	.144	.95867	.576	.272	.94955	.625
28	.268	.95996	.710	.410	.098	.774	.438
29	.125	.844	.548	.241	.94922	.590	.248
30	.95977	.686	.382	.067	.741	.403	.055
31	.823	.524	.212	.94890	.557	.214	.93860
32	.665	.357	.038	.709	.370	.021	.662
33	.502	.186	.94860	.525	.180	.93825	.461
34	.334	.011	.679	.337	.93986	.626	.257
35	.162	.94832	.494	.146	.790	.425	.051
36	.94986	.650	.306	.93952	.591	.221	.92843
37	.805	.464	.114	.756	.390	.016	.634
38	.620	.273	.93919	.556	.186	.92808	.422
39	.431	.079	.720	.353	.92979	.597	.208
40	.238	.93882	.518	.148	.770	.385	.91992
41	.042	.682	.314	.92940	.558	.170	.774
42	.93842	.478	.107	.729	.344	.91952	.554
43	.639	.271	.92897	.516	.128	.733	.332
44	.433	.062	.685	.301	.91910	.513	.108
45	.226	.92852	.472	.085	.692	.291	.90884
46	.017	.640	.257	.91868	.472	.069	.660
47	.92806	.426	.041	.649	.250	.90845	.434
48	.593	.211	.91823	.429	.028	.621	.207
49	.379	.91995	.604	.208	.90805	.396	.89979
50	.162	.776	.384	.90985	.580	.168	.750

² The density values given in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4° C as unity.

^{2a} Tables 2, 3, 4, 5, 6, 7, and 8 of this circular are based on the work done at this Bureau and published in the Bulletin of the Bureau of Standards, vol. 9, No. 3. A new interpolation of the original data has changed slightly some of the density values from those published in the previous edition of this circular.

TABLE 2.—Density (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water—Continued

Per cent alcohol by weight	Temperature						
	10° C	15° C	20° C	25° C	30° C	35° C	40° C
50	0.92162	0.91776	0.91384	0.90985	0.90580	0.90168	0.89750
51	.91943	.555	.160	.760	.353	.89940	.519
52	.723	.333	.90936	.534	.125	.710	.288
53	.502	.110	.711	.307	.89696	.479	.056
54	.279	.90885	.485	.079	.667	.248	.88623
55	.055	.659	.258	.89650	.437	.016	.589
56	.90631	.433	.031	.621	.206	.88784	.356
57	.607	.207	.89803	.392	.88975	.552	.122
58	.381	.89980	.574	.162	.744	.319	.87888
59	.154	.752	.344	.88931	.512	.085	.653
60	.89927	.523	.113	.699	.278	.87851	.417
61	.698	.293	.88882	.466	.044	.615	.180
62	.468	.062	.650	.233	.87809	.379	.86943
63	.237	.88830	.417	.87998	.574	.142	.705
64	.006	.597	.183	.763	.337	.86905	.466
65	.88774	.364	.87948	.527	.100	.667	.227
66	.541	.130	.713	.291	.86863	.429	.89987
67	.308	.87895	.477	.054	.625	.190	.747
68	.074	.660	.241	.86817	.387	.85950	.507
69	.87839	.424	.004	.579	.148	.710	.266
70	.602	.187	.86766	.340	.85908	.470	.025
71	.365	.86949	.527	.100	.667	.228	.84783
72	.127	.710	.287	.85859	.426	.84986	.540
73	.86888	.470	.047	.618	.184	.743	.297
74	.648	.229	.85806	.376	.84941	.500	.053
75	.408	.85988	.564	.134	.698	.257	.83809
76	.168	.747	.322	.84891	.455	.013	.564
77	.85927	.505	.079	.647	.211	.83768	.319
78	.685	.262	.84835	.403	.83966	.523	.074
79	.442	.018	.590	.158	.720	.277	.82827
80	.197	.84772	.344	.83911	.473	.029	.578
81	.84950	.525	.096	.664	.224	.82780	.329
82	.702	.277	.83848	.415	.82974	.530	.079
83	.453	.028	.599	.164	.724	.279	.81828
84	.203	.83777	.348	.82913	.473	.027	.576
85	.83951	.525	.095	.660	.220	.81774	.322
86	.697	.271	.82840	.405	.81965	.519	.067
87	.441	.014	.583	.148	.708	.262	.80811
88	.181	.82754	.323	.81888	.448	.003	.552
89	.82919	.492	.062	.626	.186	.80742	.291
90	.654	.227	.81797	.362	.80922	.478	.028
91	.386	.81959	.529	.094	.655	.211	.79761
92	.114	.688	.257	.80823	.384	.79941	.491
93	.81839	.413	.80983	.549	.111	.609	.230
94	.561	.134	.705	.272	.79835	.393	.78947
95	.278	.80852	.424	.79991	.555	.114	.670
96	.80991	.566	.138	.706	.271	.78831	.388
97	.698	.274	.79846	.415	.78981	.542	.100
98	.399	.79973	.547	.117	.684	.247	.77806
99	.094	.670	.243	.78814	.382	.77946	.507
100	.79784	.360	.78934	.506	.075	.641	.203

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TABLE 3.—Density^{2b} (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water at 20° C

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.99823	804	785	766	748	729	710	692	673	655
1	636	618	599	581	562	544	525	507	489	471
2	453	435	417	399	381	363	345	327	310	292
3	275	257	240	222	205	188	171	154	137	120
4	103	087	070	053	037	020	003	*987	*971	*954
5	.98938	922	906	890	874	859	843	827	811	796
6	780	765	749	734	718	703	688	673	658	642
7	627	612	597	582	567	553	538	523	508	493
8	478	463	449	434	419	404	389	374	360	345
9	331	316	301	287	273	258	244	229	215	201
10	187	172	158	144	130	117	103	089	075	061
11	047	033	019	006	*992	*978	*964	*951	*937	*923
12	.97910	896	883	869	855	842	828	815	801	788
13	775	761	748	735	722	709	696	683	670	657
14	643	630	617	604	591	578	565	552	539	526
15	514	501	488	475	462	450	438	425	412	400
16	387	374	361	349	336	323	310	297	284	272
17	259	246	233	220	207	194	181	168	155	142
18	129	116	103	089	076	063	050	037	024	010
19	.96997	984	971	957	944	931	917	904	891	877
20	864	850	837	823	810	796	783	769	756	742
21	729	716	702	688	675	661	647	634	620	606
22	592	578	564	551	537	523	509	495	481	467
23	453	439	425	411	396	382	368	354	340	326
24	312	297	283	269	254	240	225	211	196	182
25	168	153	139	124	109	094	080	065	050	035
26	020	005	*990	*975	*959	*944	*929	*914	*898	*883
27	.95867	851	836	820	805	789	773	757	742	726
28	710	694	678	662	646	630	613	597	581	565
29	548	532	516	499	483	466	450	433	416	400
30	382	365	349	332	315	298	281	264	247	230
31	212	195	178	161	143	126	108	091	074	056
32	038	020	003	*985	*967	*950	*932	*914	*896	*878
33	.94860	842	824	806	788	770	752	734	715	697
34	679	660	642	624	605	587	568	550	531	512
35	494	475	456	438	419	400	382	363	344	325
36	306	287	268	249	230	211	192	172	153	134
37	114	095	075	056	036	017	*997	*978	*958	*939
38	.93919	899	879	859	840	820	800	780	760	740
39	720	700	680	660	640	620	599	579	559	539
40	518	498	478	458	437	417	396	376	356	335
41	314	294	273	253	232	212	191	170	149	129
42	107	086	065	044	023	002	*981	*960	*939	*918
43	.92897	876	855	834	812	791	770	749	728	707
44	685	664	642	621	600	579	557	536	515	493
45	472	450	429	408	386	365	343	322	300	279
46	257	236	214	193	171	150	128	106	085	063
47	041	019	*997	*976	*954	*932	*910	*889	*867	*845
48	.91823	801	780	758	736	714	692	670	648	626
49	604	582	560	538	516	494	472	450	428	406
50	384	361	339	317	295	272	250	228	206	183

^{2b} The density values given in this table are numerically the same as specific gravity at 20° C in terms of water at 4° C as unity.

TABLE 3.—Density (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water, at 20° C—Continued

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	0.91384	361	339	317	295	272	250	228	206	183
51	160	138	116	093	071	049	026	004	*981	*959
52	.90936	914	891	869	846	824	801	779	756	734
53	711	689	666	644	621	598	576	553	531	508
54	485	463	440	417	395	372	349	327	304	281
55	258	236	213	190	167	145	122	099	076	054
56	031	008	*985	*962	*939	*917	*894	*871	*848	*825
57	.89803	780	757	734	711	688	665	643	620	597
58	574	551	528	505	482	459	436	413	390	367
59	344	321	298	275	252	229	206	183	160	137
60	113	090	067	044	021	*998	*975	*951	*928	*905
61	.88882	859	836	812	789	766	743	720	696	673
62	650	626	603	580	557	533	510	487	463	440
63	417	393	370	347	323	300	277	253	230	206
64	183	160	136	113	089	066	042	019	*995	*972
65	.87948	925	901	878	854	831	807	784	760	737
66	713	689	666	642	619	595	572	548	524	501
67	477	454	430	406	383	359	336	312	288	265
68	241	218	194	170	147	123	099	075	052	028
69	004	*981	*957	*933	*909	*885	*862	*838	*814	*790
70	.86766	742	718	694	671	647	623	599	575	551
71	527	503	479	455	431	407	383	359	335	311
72	287	263	239	215	191	167	143	119	095	071
73	047	022	*998	*974	*950	*926	*902	*878	*854	*830
74	.85806	781	757	733	709	685	661	636	612	588
75	564	540	515	491	467	443	419	394	370	346
76	322	297	273	249	225	200	176	152	128	103
77	079	055	031	006	*982	*958	*933	*909	*884	*860
78	.84835	811	787	762	738	713	689	664	640	615
79	590	566	541	517	492	467	443	418	393	369
80	344	319	294	270	245	220	196	171	146	121
81	096	072	047	022	*997	*972	*947	*923	*898	*873
82	.83848	823	798	773	748	723	698	674	649	624
83	599	574	549	523	498	473	448	423	398	373
84	348	323	297	272	247	222	196	171	146	120
85	095	070	044	019	*994	*968	*943	*917	*892	*866
86	.82840	815	789	763	738	712	686	660	635	609
87	583	557	531	505	479	453	427	401	375	349
88	323	297	271	245	219	193	167	140	114	088
89	062	035	009	*983	*956	*930	*903	*877	*850	*824
90	.81797	770	744	717	690	664	637	610	583	556
91	529	502	475	448	421	394	366	339	312	285
92	257	230	203	175	148	120	093	066	038	010
93	.80883	955	928	900	872	844	817	789	761	733
94	705	677	649	621	593	565	537	509	480	452
95	424	395	367	338	310	281	253	224	195	166
96	138	109	080	051	022	*993	*963	*934	*905	*875
97	.79846	816	787	757	727	698	668	638	608	578
98	547	517	487	456	426	396	365	335	305	274
99	243	213	182	151	120	089	059	028	*997	*966
100	.78934									

TABLE 4.—Specific Gravity at 60° F (15° C) of Mixtures (by Volume) of Ethyl Alcohol and Water

Per Cent Alcohol by Volume at 60° F	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	1.00000	*985	*970	*955	*940	*925	*910	*895	*880	*865
1	.99850	835	820	806	791	776	761	747	732	717
2	703	688	674	659	645	630	616	602	587	573
3	559	545	531	516	502	488	474	460	446	432
4	419	405	391	378	364	350	336	323	309	296
5	282	269	255	242	228	215	202	189	176	163
6	150	137	124	111	098	085	073	060	047	035
7	022	009	*997	*984	*972	*960	*947	*935	*923	*911
8	.98999	887	875	863	851	838	826	814	803	791
9	779	767	755	743	731	720	708	696	684	672
10	661	649	637	625	614	602	590	579	567	556
11	544	532	521	509	498	487	475	464	452	441
12	430	419	408	396	385	374	363	352	341	330
13	319	308	297	286	275	264	254	243	232	221
14	210	200	190	179	168	157	147	136	125	115
15	104	093	083	072	062	051	040	030	019	009
16	.97998	988	977	967	956	946	936	925	915	905
17	895	885	875	864	854	844	834	824	814	804
18	794	784	774	764	754	744	734	724	714	704
19	694	684	674	664	654	645	635	625	615	605
20	596	586	576	566	556	546	536	526	516	506
21	496	486	476	466	456	446	436	425	415	405
22	395	385	375	365	354	344	334	324	313	303
23	293	283	272	262	252	241	231	221	210	200
24	189	179	168	158	147	137	126	116	105	095
25	084	073	063	052	042	031	020	010	*999	*988
26	.96978	967	957	946	935	924	914	903	892	881
27	870	859	848	837	826	815	804	793	782	771
28	760	749	738	727	715	704	693	682	671	659
29	648	637	625	614	603	591	580	568	557	546
30	534	522	511	499	488	476	464	453	441	429
31	418	406	394	382	370	358	346	334	321	309
32	296	284	271	259	246	234	221	209	196	183
33	170	157	144	132	119	106	093	080	067	054
34	041	028	015	002	*988	*975	*962	*948	*935	*921
35	.95908	894	881	867	854	840	826	812	798	784
36	770	756	742	728	714	700	685	671	657	643
37	628	614	599	585	570	556	541	526	512	497
38	482	467	452	437	423	408	393	378	362	347
39	332	317	302	286	271	256	240	225	209	194
40	178	162	147	131	115	100	084	068	052	036
41	020	004	*988	*972	*956	*940	*923	*907	*891	*875
42	.94858	842	825	809	792	776	759	743	726	710
43	693	676	660	643	626	609	592	575	558	541
44	524	507	490	473	455	438	421	403	386	369
45	351	334	316	298	281	263	245	228	210	192
46	174	156	138	120	102	084	066	048	030	011
47	.93993	975	956	938	920	901	883	864	845	827
48	808	789	771	752	733	714	695	676	657	638
49	619	600	581	562	543	523	504	485	465	446
50	426	407	387	368	348	328	309	289	270	250

TABLE 4.—Specific Gravity at 60° F (15° 56 C) of Mixtures (by Volume) of Ethyl Alcohol and Water—Continued

Per Cent Alcohol by Volume at 60° F	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	.93426	407	387	368	348	328	309	289	270	250
51	230	210	190	171	151	131	111	091	071	051
52	031	011	^{*991}	^{*971}	^{*951}	^{*931}	^{*911}	^{*890}	^{*870}	^{*850}
53	.92830	810	789	769	749	728	708	688	667	647
54	626	605	585	564	544	523	502	482	461	440
55	419	398	377	357	336	315	294	273	252	231
56	210	189	168	147	126	105	084	062	041	020
57	.91999	978	956	935	914	892	871	849	827	806
58	784	762	741	719	697	675	653	631	610	588
59	565	543	521	499	477	455	433	410	388	366
60	344	322	299	277	255	232	210	188	165	143
61	120	097	075	052	030	007	^{*984}	^{*962}	^{*939}	^{*916}
62	.90893	870	847	825	802	779	756	733	710	687
63	664	641	618	595	572	549	526	503	480	457
64	434	411	388	365	341	318	295	272	249	225
65	202	179	155	132	108	085	061	038	014	^{*991}
66	.89967	943	920	896	872	848	825	801	777	753
67	729	705	681	657	633	609	585	561	537	513
68	489	465	441	416	392	368	343	319	295	270
69	245	220	196	171	147	122	098	073	048	024
70	.88999	974	950	925	900	875	850	825	801	776
71	751	725	700	675	650	625	600	574	549	524
72	499	474	448	423	397	372	346	321	296	270
73	244	218	193	167	141	116	090	064	039	013
74	.87987	961	935	910	884	858	832	806	780	754
75	728	702	676	650	623	597	571	545	518	492
76	465	439	412	386	359	332	306	279	252	226
77	199	172	145	118	092	065	038	011	^{*984}	^{*957}
78	.86929	902	875	847	820	793	766	738	711	684
79	656	629	601	574	546	518	491	463	435	408
80	380	352	324	296	269	241	213	185	157	129
81	100	072	044	015	^{*987}	^{*959}	^{*931}	^{*902}	^{*874}	^{*846}
82	.85817	789	760	732	702	674	646	617	588	560
83	531	502	473	444	415	386	357	328	299	270
84	240	211	181	152	122	093	063	033	004	^{*974}
85	.84944	914	884	854	824	794	764	734	703	673
86	642	612	581	551	520	490	459	428	398	367
87	336	305	274	243	212	181	150	119	088	056
88	025	^{*994}	^{*962}	^{*930}	^{*899}	^{*867}	^{*835}	^{*803}	^{*771}	^{*739}
89	.83707	675	643	610	578	545	513	480	447	415
90	382	349	315	282	249	216	183	150	116	083
91	049	015	^{*981}	^{*947}	^{*912}	^{*879}	^{*845}	^{*810}	^{*776}	^{*741}
92	.82705	670	635	600	565	529	494	458	423	387
93	351	315	279	243	206	170	133	096	059	022
94	.81984	947	909	871	834	796	757	719	681	642
95	603	564	525	486	446	407	367	327	287	247
96	206	165	125	084	042	001	^{*960}	^{*918}	^{*876}	^{*834}
97	.80792	750	707	664	620	577	533	489	445	401
98	356	311	265	219	173	127	080	033	^{*985}	^{*937}
99	.79889	841	792	743	693	643	593	543	492	441
100	389									

TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which Tables 2, 3, 4, 6, 7, and 8 are calculated. The hydrometer is assumed to be of Jena 16^{III} glass. For the per cents not given between 40 and 80, linear interpolation of the tabulated corrections will give results sufficiently exact for most purposes.]

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume												
	0	1	2	3	4	5	6	7	8	9	10	11	12
	Add to Observed Per Cent Alcohol												
50	0.37	0.38	0.39	0.40	0.42	0.45	0.48	0.52	0.56	0.61	0.66	0.74	0.81
51	.34	.35	.36	.37	.39	.41	.44	.47	.51	.56	.61	.68	.75
52	.32	.32	.33	.34	.35	.38	.40	.43	.47	.51	.55	.62	.68
53	.29	.30	.30	.31	.32	.34	.36	.39	.42	.46	.49	.55	.60
54	.26	.26	.26	.27	.28	.29	.32	.34	.36	.40	.43	.48	.52
55	.22	.22	.23	.23	.24	.25	.27	.29	.31	.34	.37	.40	.44
56	.18	.18	.18	.18	.19	.20	.22	.24	.25	.28	.30	.33	.36
57	.14	.14	.14	.14	.14	.15	.17	.18	.19	.21	.23	.25	.27
58	.09	.10	.10	.10	.10	.10	.11	.12	.13	.14	.16	.16	.18
59	.05	.05	.05	.05	.05	.05	.06	.06	.06	.07	.08	.08	.09
Subtract from Observed Per Cent Alcohol													
61		0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10
62		.10	.11	.12	.12	.13	.14	.14	.16	.16	.17	.18	.20
63		.16	.17	.18	.19	.20	.20	.21	.23	.24	.25	.27	.29
64		.22	.23	.24	.25	.26	.27	.29	.31	.32	.34	.37	.39
65		.28	.29	.30	.32	.33	.34	.36	.39	.41	.43	.46	.49
66		.34	.35	.36	.38	.40	.42	.44	.47	.50	.52	.56	.59
67		.41	.42	.43	.45	.47	.50	.52	.55	.58	.61	.65	.70
68		.48	.48	.50	.52	.54	.57	.60	.64	.67	.71	.75	.80
69		.55	.56	.57	.59	.62	.66	.68	.73	.76	.80	.85	.91
70		.62	.63	.64	.67	.70	.74	.77	.81	.86	.90	.96	1.02
72		.77	.78	.80	.83	.86	.90	.94	.99	1.04	1.10	1.16	1.23
74		.93	.94	.96	1.00	1.03	1.09	1.13	1.18	1.25	1.32	1.39	1.46
76			1.10	1.13	1.17	1.21	1.27	1.32	1.38	1.46	1.54	1.61	1.70
78			1.28	1.31	1.35	1.40	1.46	1.52	1.59	1.67	1.76	1.84	1.94
80			1.46	1.50	1.54	1.60	1.66	1.73	1.80	1.89	1.99	2.09	2.20
82			1.64	1.69	1.74	1.80	1.87	1.94	2.02	2.12	2.22	2.34	2.45
84			1.84	1.89	1.94	2.00	2.08	2.16	2.25	2.35	2.47	2.59	2.71
86				2.09	2.15	2.22	2.30	2.39	2.49	2.60	2.72	2.84	2.97
88				2.30	2.37	2.44	2.53	2.62	2.73	2.85	2.98	3.10	3.23
90				2.52	2.59	2.66	2.76	2.86	2.98	3.11	3.24	3.36	3.50
92				2.74	2.82	2.89	3.00	3.11	3.24	3.37	3.51	3.64	3.78
94				2.97	3.04	3.12	3.24	3.36	3.50	3.63	3.78	3.92	4.07
96					3.28	3.36	3.49	3.62	3.76	3.90	4.05	4.20	4.36
98					3.52	3.60	3.74	3.88	4.03	4.17	4.32	4.50	4.66
100					3.76	3.85	4.00	4.15	4.30	4.45	4.60	4.78	4.95

TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume											
	13	14	15	16	17	18	19	20	21	22	23	24
	Add to Observed Per Cent Alcohol											
50	0.90	0.99	1.09	1.19	1.30	1.41	1.52	1.62	1.72	1.82	1.90	1.98
51	.82	.90	.99	1.08	1.18	1.28	1.38	1.47	1.56	1.64	1.71	1.79
52	.74	.80	.89	.96	1.06	1.14	1.23	1.31	1.38	1.46	1.52	1.58
53	.65	.71	.78	.85	.94	1.00	1.08	1.15	1.21	1.28	1.34	1.39
54	.57	.62	.68	.74	.81	.86	.94	.99	1.04	1.10	1.15	1.20
55	.48	.52	.57	.62	.68	.72	.78	.83	.87	.92	.96	1.00
56	.38	.42	.46	.49	.54	.58	.63	.67	.69	.74	.77	.80
57	.29	.32	.35	.37	.40	.44	.47	.51	.53	.56	.58	.60
58	.19	.21	.23	.24	.26	.29	.32	.34	.35	.38	.40	.40
59	.10	.11	.12	.12	.13	.14	.16	.17	.18	.19	.20	.20
	Subtract from Observed Per Cent Alcohol											
	61	62	63	64	65	66	67	68	69	70	72	74
	76	78	80	82	84	86	88	90	92	94	96	98
61	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.18
62	.21	.22	.24	.26	.27	.29	.30	.32	.34	.36	.37	.38
63	.31	.32	.35	.38	.41	.44	.46	.49	.51	.53	.55	.56
64	.42	.44	.48	.52	.54	.58	.62	.66	.68	.71	.74	.77
65	.52	.55	.60	.65	.68	.73	.78	.82	.85	.90	.92	.96
66	.63	.66	.71	.77	.82	.88	.94	.98	1.02	1.07	1.11	1.16
67	.74	.78	.84	.90	.96	1.03	1.10	1.15	1.20	1.25	1.30	1.35
68	.85	.91	.97	1.03	1.10	1.18	1.26	1.33	1.38	1.44	1.49	1.54
69	.97	1.02	1.10	1.17	1.25	1.33	1.42	1.48	1.54	1.61	1.66	1.72
70	1.08	1.14	1.23	1.31	1.40	1.49	1.58	1.65	1.72	1.78	1.84	1.91
72	1.31	1.39	1.50	1.60	1.70	1.80	1.90	2.00	2.06	2.13	2.20	2.27
74	1.55	1.65	1.76	1.88	1.99	2.10	2.22	2.32	2.41	2.48	2.56	2.65
76	1.80	1.91	2.03	2.16	2.28	2.41	2.54	2.65	2.76	2.84	2.93	3.03
78	2.05	2.17	2.30	2.44	2.58	2.72	2.86	2.98	3.10	3.20	3.30	3.40
80	2.31	2.44	2.58	2.72	2.87	3.02	3.17	3.33	3.45	3.56	3.67	3.78
82	2.57	2.71	2.86	3.00	3.16	3.33	3.50	3.66	3.79	3.92	4.04	4.18
84	2.84	2.98	3.13	3.29	3.46	3.63	3.81	4.00	4.14	4.28	4.42	4.56
86	3.11	3.26	3.41	3.58	3.76	3.94	4.13	4.33	4.49	4.65	4.80	4.94
88	3.38	3.54	3.70	3.88	4.07	4.26	4.46	4.67	4.84	5.00	5.17	5.32
90	3.66	3.83	4.00	4.18	4.38	4.58	4.78	5.01	5.19	5.36	5.53	5.69
92	3.94	4.11	4.29	4.48	4.69	4.90	5.12	5.35	5.54	5.72	5.90	6.07
94	4.23	4.40	4.58	4.79	5.00	5.22	5.46	5.69	5.89	6.08	6.28	6.45
96	4.53	4.69	4.87	5.10	5.32	5.55	5.80	6.03	6.24	6.44	6.64	6.82
98	4.83	5.00	5.18	5.41	5.64	5.88	6.13	6.38	6.60	6.80	7.02	7.20
100	5.13	5.30	5.49	5.72	5.95	6.21	6.46	6.72	6.95	7.17	7.40	7.59

TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	25	26	27	28	29	30	31	32	33	34	35
	Add to Observed Per Cent Alcohol										
50	2.06	2.12	2.18	2.24	2.28	2.31	2.32	2.32	2.32	2.31	2.29
51	1.85	1.90	1.96	2.02	2.05	2.08	2.10	2.09	2.09	2.08	2.07
52	1.64	1.69	1.74	1.78	1.82	1.84	1.85	1.86	1.86	1.85	1.84
53	1.44	1.48	1.52	1.56	1.58	1.60	1.61	1.62	1.63	1.62	1.61
54	1.24	1.27	1.30	1.34	1.36	1.36	1.38	1.39	1.40	1.38	1.38
55	1.03	1.06	1.08	1.10	1.12	1.13	1.14	1.15	1.16	1.15	1.15
56	.82	.85	.87	.89	.90	.90	.91	.92	.92	.92	.92
57	.62	.64	.65	.66	.67	.67	.68	.69	.70	.69	.69
58	.41	.42	.43	.44	.44	.44	.45	.46	.46	.46	.46
59	.21	.21	.21	.22	.22	.22	.22	.22	.23	.23	.23
	Subtract from Observed Per Cent Alcohol										
	61	62	63	64	65	66	67	68	69	70	
	0.19	0.20	0.20	0.21	0.22	0.23	0.23	0.23	0.23	0.23	0.23
61	.39	.40	.41	.42	.44	.46	.46	.46	.46	.46	.46
62	.59	.60	.62	.64	.66	.68	.68	.68	.68	.68	.68
63	.79	.80	.83	.86	.88	.91	.91	.91	.91	.91	.91
64	.99	1.00	1.04	1.08	1.10	1.12	1.13	1.13	1.14	1.14	1.14
65	1.19	1.21	1.25	1.30	1.32	1.35	1.36	1.36	1.36	1.36	1.36
66	1.39	1.41	1.45	1.50	1.54	1.57	1.58	1.59	1.60	1.60	1.60
67	1.58	1.64	1.68	1.72	1.76	1.79	1.80	1.81	1.82	1.82	1.82
68	1.77	1.82	1.86	1.91	1.96	2.00	2.02	2.03	2.04	2.04	2.04
69	1.97	2.02	2.08	2.12	2.18	2.22	2.24	2.26	2.27	2.27	2.27
70	2.36	2.42	2.48	2.54	2.60	2.66	2.68	2.70	2.71	2.72	2.72
72	2.74	2.81	2.88	2.96	3.04	3.10	3.12	3.15	3.16	3.18	3.18
74	3.14	3.21	3.30	3.38	3.46	3.52	3.56	3.58	3.60	3.63	3.64
76	3.51	3.61	3.70	3.78	3.86	3.95	3.99	4.03	4.06	4.08	4.09
78	3.90	4.00	4.10	4.19	4.28	4.37	4.42	4.48	4.51	4.53	4.54
80	4.29	4.40	4.50	4.60	4.70	4.80	4.86	4.91	4.95	4.98	5.00
82	4.68	4.80	4.91	5.02	5.12	5.24	5.30	5.35	5.40	5.42	5.44
84	5.07	5.20	5.32	5.44	5.54	5.64	5.72	5.79	5.84	5.88	5.90
86	5.46	5.60	5.72	5.84	5.95	6.06	6.14	6.20	6.26	6.31	6.34
88	5.84	5.98	6.12	6.24	6.36	6.46	6.55	6.62	6.68	6.74	6.78
90	6.23	6.38	6.52	6.66	6.77	6.87	6.97	7.04	7.12	7.18	7.22
92	6.62	6.78	6.93	7.06	7.18	7.29	7.38	7.47	7.54	7.61	7.66
94	7.00	7.17	7.32	7.46	7.60	7.71	7.82	7.90	7.98	8.06	8.10
96	7.40	7.57	7.72	7.87	8.01	8.12	8.24	8.33	8.42	8.50	8.54
98	7.78	7.96	8.12	8.28	8.42	8.55	8.68	8.76	8.84	8.93	9.00
100											

TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	36	37	38	39	40	45	50	55	60	65	70
	Add to Observed Per Cent Alcohol										
50	2.28	2.27	2.26	2.25	2.24	2.14	2.04	1.98	1.90	1.85	1.78
51	2.06	2.04	2.03	2.03	2.02	1.91	1.84	1.78	1.71	1.66	1.60
52	1.82	1.80	1.80	1.80	1.79	1.71	1.64	1.58	1.52	1.47	1.42
53	1.60	1.58	1.58	1.58	1.56	1.50	1.44	1.38	1.33	1.29	1.25
54	1.37	1.36	1.36	1.36	1.34	1.28	1.23	1.19	1.14	1.11	1.08
55	1.14	1.13	1.13	1.13	1.11	1.06	1.02	.99	.95	.92	.90
56	.91	.90	.90	.90	.89	.85	.81	.79	.76	.74	.72
57	.68	.67	.68	.68	.67	.64	.61	.59	.57	.55	.54
58	.46	.46	.46	.46	.45	.42	.40	.39	.39	.38	.36
59	.23	.23	.23	.23	.23	.21	.20	.20	.19	.18	.18
	Subtract from Observed Per Cent Alcohol										
	61	62	63	64	65	66	67	68	69	70	71
	72	74	76	78	80	82	84	86	88	90	92
61	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.20	0.20	0.18	0.18
62	.46	.46	.46	.45	.45	.44	.42	.40	.39	.38	.36
63	.68	.68	.68	.68	.68	.66	.62	.60	.58	.56	.54
64	.92	.92	.91	.90	.90	.87	.84	.81	.78	.75	.72
65	1.14	1.14	1.13	1.12	1.12	1.09	1.05	1.01	.97	.94	.90
66	1.37	1.36	1.36	1.35	1.34	1.30	1.25	1.21	1.17	1.13	1.09
67	1.60	1.60	1.60	1.58	1.56	1.52	1.46	1.41	1.37	1.32	1.27
68	1.82	1.82	1.81	1.80	1.79	1.74	1.66	1.61	1.55	1.50	1.45
69	2.04	2.03	2.03	2.03	2.01	1.96	1.88	1.81	1.75	1.69	1.63
70	2.27	2.27	2.26	2.25	2.24	2.17	2.09	2.02	1.95	1.88	1.82
72	2.72	2.72	2.72	2.70	2.68	2.61	2.51	2.42	2.34	2.26	2.18
74	3.18	3.17	3.17	3.16	3.14	3.04	2.93	2.83	2.73	2.65	2.56
76	3.63	3.62	3.62	3.60	3.58	3.47	3.35	3.24	3.13	3.03	2.93
78	4.09	4.08	4.07	4.06	4.02	3.92	3.78	3.64	3.53	3.42	3.30
80	4.54	4.53	4.52	4.50	4.48	4.36	4.20	4.05	3.93	3.80	3.68
82	5.00	4.98	4.98	4.96	4.94	4.81	4.63	4.47	4.33	4.19	4.06
84	5.45	5.44	5.43	5.40	5.38	5.25	5.06	4.88	4.73	4.58	4.44
86	5.90	5.89	5.88	5.86	5.84	5.70	5.49	5.30	5.14	4.98	4.82
88	6.35	6.34	6.33	6.31	6.29	6.14	5.92	5.72	5.54	5.37	5.20
90	6.80	6.80	6.78	6.76	6.73	6.58	6.36	6.14	5.95	5.76	5.59
92	7.25	7.25	7.22	7.20	7.18	7.03	6.80	6.56	6.36	6.16	5.98
94	7.70	7.70	7.67	7.66	7.63	7.48	7.24	6.98	6.77	6.56	6.37
96	8.14	8.15	8.12	8.11	8.08	7.92	7.68	7.40	7.19	6.96	6.76
98	8.58	8.60	8.58	8.56	8.54	8.36	8.11	7.82	7.60	7.36	7.15
100	9.03	9.04	9.03	9.01	8.98	8.81	8.45	8.25	8.02	7.76	7.54

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TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	75	80	81	82	83	84	85	86	87	88	89
	Add to Observed Per Cent Alcohol										
50	1.71	1.63	1.62	1.60	1.58	1.56	1.53	1.51	1.48	1.46	1.43
51	1.54	1.47	1.46	1.44	1.42	1.40	1.38	1.36	1.33	1.31	1.28
52	1.36	1.30	1.30	1.28	1.26	1.24	1.22	1.20	1.18	1.16	1.14
53	1.20	1.15	1.14	1.12	1.11	1.09	1.07	1.06	1.04	1.02	1.00
54	1.04	.98	.98	.96	.95	.94	.92	.91	.89	.88	.86
55	.87	.82	.81	.80	.79	.78	.76	.75	.74	.74	.72
56	.70	.66	.65	.64	.63	.62	.61	.60	.59	.58	.57
57	.53	.49	.49	.49	.48	.47	.46	.46	.45	.44	.43
58	.34	.32	.32	.32	.31	.30	.30	.30	.30	.29	.28
59	.17	.16	.16	.16	.16	.15	.15	.15	.15	.15	.14
	Subtract from Observed Per Cent Alcohol										
	61	62	63	64	65	66	67	68	69	70	71
	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15
61	.34	.34	.34	.32	.32	.32	.32	.31	.31	.31	.30
62	.52	.50	.50	.48	.48	.48	.48	.47	.46	.46	.44
63	.70	.68	.66	.65	.65	.64	.63	.62	.61	.60	.59
64	.86	.84	.82	.82	.81	.80	.79	.78	.77	.76	.74
65	1.05	1.00	.99	.98	.97	.96	.94	.93	.92	.90	.88
66	1.22	1.17	1.16	1.14	1.13	1.12	1.10	1.09	1.08	1.06	1.02
67	1.40	1.33	1.32	1.31	1.29	1.28	1.26	1.24	1.22	1.20	1.17
68	1.57	1.50	1.49	1.47	1.46	1.44	1.42	1.40	1.38	1.36	1.32
69	1.75	1.68	1.66	1.64	1.62	1.60	1.58	1.56	1.54	1.51	1.48
70	2.10	2.02	2.00	1.97	1.95	1.93	1.90	1.88	1.85	1.82	1.78
71	2.46	2.36	2.34	2.30	2.28	2.26	2.24	2.20	2.17	2.13	2.09
72	2.81	2.70	2.68	2.64	2.61	2.59	2.56	2.52	2.48	2.44	2.40
73	3.18	3.04	3.02	2.98	2.94	2.92	2.88	2.84	2.80	2.76	2.71
74	3.54	3.38	3.36	3.32	3.28	3.26	3.22	3.17	3.13	3.08	3.02
75	3.90	3.72	3.71	3.66	3.62	3.59	3.54	3.50	3.45	3.40	3.33
76	4.27	4.08	4.05	4.00	3.96	3.92	3.88	3.83	3.77	3.72	3.65
77	4.64	4.43	4.39	4.35	4.30	4.26	4.21	4.16	4.10	4.04	3.96
78	5.00	4.78	4.75	4.70	4.65	4.60	4.55	4.50	4.44	4.37	4.29
79	5.37	5.14	5.10	5.06	5.00	4.95	4.88	4.83	4.77	4.70	4.61
80	5.75	5.50	5.46	5.42	5.36	5.30	5.23	5.18	5.10	5.03	4.94
81	6.12	5.86	5.81	5.76	5.70	5.64	5.58	5.51	5.44	5.36	5.26
82	6.50	6.23	6.17	6.12	6.06	5.99	5.92	5.86	5.78	5.69	5.59
83	6.88	6.60	6.50	6.48	6.41	6.34	6.26	6.20	6.11	6.02	5.92
84	7.26	6.96	6.89	6.84	6.76	6.70	6.61	6.54	6.44	6.36	6.26

TABLE 5.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	90	91	92	93	94	95	96	97	98	99	100
	Add to Observed Per Cent Alcohol										
50	1.39	1.36	1.32	1.27	1.22	1.17	1.12	1.06	0.99	0.93	.....
51	1.25	1.22	1.18	1.14	1.10	1.06	1.01	.95	.89	.84	.....
52	1.12	1.09	1.06	1.02	.98	.94	.90	.85	.79	.74	.....
53	.98	.96	.93	.90	.86	.83	.79	.74	.70	.65	.....
54	.84	.82	.80	.77	.74	.72	.68	.64	.60	.56	.....
55	.70	.69	.66	.64	.62	.60	.57	.53	.50	.47	.....
56	.56	.55	.53	.52	.49	.48	.45	.43	.40	.38	.....
57	.42	.41	.40	.39	.37	.36	.34	.32	.30	.29	.....
58	.28	.27	.26	.26	.24	.24	.23	.21	.20	.19	.....
59	.14	.14	.13	.13	.12	.12	.12	.11	.10	.10	.....
	Subtract from Observed Per Cent Alcohol										
61	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.10	0.09
62	.29	.28	.27	.26	.25	.24	.23	.22	.21	.19	.18
63	.43	.42	.41	.39	.38	.36	.35	.33	.31	.29	.27
64	.58	.55	.54	.52	.51	.49	.46	.44	.41	.39	.36
65	.72	.70	.68	.66	.64	.61	.58	.55	.52	.49	.46
66	.86	.84	.82	.79	.76	.73	.70	.67	.63	.59	.55
67	1.00	.98	.96	.93	.90	.86	.82	.78	.74	.70	.64
68	1.15	1.12	1.09	1.06	1.02	.98	.94	.90	.85	.80	.74
69	1.30	1.26	1.23	1.20	1.16	1.10	1.06	1.02	.96	.90	.84
70	1.45	1.41	1.37	1.34	1.29	1.23	1.19	1.14	1.07	1.00	.94
72	1.74	1.70	1.65	1.61	1.55	1.49	1.43	1.37	1.30	1.22	1.13
74	2.05	2.00	1.94	1.89	1.82	1.75	1.69	1.61	1.53	1.43	1.33
76	2.35	2.29	2.23	2.17	2.09	2.01	1.94	1.85	1.76	1.65	1.53
78	2.65	2.59	2.52	2.46	2.36	2.28	2.20	2.10	2.00	1.87	1.73
80	2.96	2.89	2.82	2.74	2.64	2.56	2.46	2.35	2.24	2.09	1.93
82	3.26	3.20	3.12	3.03	2.92	2.84	2.72	2.60	2.48	2.32	2.14
84	3.57	3.50	3.39	3.32	3.21	3.10	2.96	2.86	2.73	2.56	2.36
86	3.89	3.80	3.72	3.62	3.51	3.38	3.26	3.13	2.98	2.80	2.58
88	4.20	4.12	4.02	3.91	3.80	3.66	3.54	3.39	3.24	3.06	2.81
90	4.52	4.42	4.32	4.20	4.08	3.94	3.81	3.66	3.50	3.30	3.08
92	4.84	4.74	4.62	4.50	4.38	4.23	4.10	3.93	3.76	3.55	3.26
94	5.16	5.06	4.94	4.80	4.67	4.52	4.38	4.20	4.02	3.80	3.50
96	5.49	5.39	5.25	5.11	4.97	4.82	4.67	4.48	4.29	4.06	3.73
98	5.82	5.70	5.56	5.42	5.27	5.12	4.95	4.76	4.55	4.31	3.96
100	6.15	6.02	5.88	5.74	5.58	5.42	5.24	5.04	4.82	4.56	4.21

TABLE 6.—Percentages by Volume at 60° F, Corresponding to Various Percentages by Weight in Mixtures of Ethyl Alcohol and Water

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.000	0.126	0.252	0.378	0.504	0.630	0.755	0.881	1.007	1.132
1	1.257	1.382	1.508	1.633	1.759	1.884	2.009	2.134	2.260	2.385
2	2.510	2.635	2.760	2.885	3.010	3.135	3.259	3.384	3.509	3.633
3	3.758	3.883	4.007	4.132	4.256	4.381	4.505	4.629	4.754	4.878
4	5.002	5.126	5.250	5.374	5.499	5.623	5.747	5.871	5.995	6.119
5	6.243	6.367	6.491	6.614	6.738	6.862	6.985	7.109	7.232	7.356
6	7.479	7.602	7.726	7.849	7.972	8.096	8.219	8.342	8.466	8.589
7	8.712	8.835	8.958	9.081	9.205	9.328	9.451	9.574	9.697	9.820
8	9.943	10.066	10.189	10.311	10.434	10.557	10.679	10.802	10.925	11.047
9	11.169	11.292	11.414	11.536	11.659	11.781	11.904	12.026	12.149	12.271
10	12.393	12.515	12.637	12.760	12.882	13.004	13.126	13.248	13.370	13.492
11	13.613	13.735	13.857	13.979	14.101	14.223	14.345	14.466	14.588	14.710
12	14.832	14.954	15.075	15.197	15.319	15.440	15.562	15.683	15.805	15.926
13	16.047	16.168	16.290	16.411	16.532	16.654	16.775	16.896	17.017	17.138
14	17.259	17.380	17.501	17.622	17.743	17.864	17.985	18.106	18.227	18.348
15	18.469	18.590	18.711	18.832	18.952	19.073	19.194	19.315	19.435	19.556
16	19.676	19.797	19.917	20.038	20.158	20.279	20.399	20.519	20.640	20.760
17	20.880	21.000	21.120	21.241	21.361	21.481	21.601	21.721	21.841	21.961
18	22.081	22.201	22.321	22.441	22.561	22.680	22.800	22.919	23.039	23.159
19	23.278	23.398	23.517	23.636	23.756	23.876	23.995	24.114	24.234	24.353
20	24.472	24.591	24.710	24.829	24.949	25.068	25.187	25.305	25.424	25.543
21	25.662	25.781	25.900	26.018	26.137	26.256	26.375	26.493	26.612	26.730
22	26.849	26.968	27.086	27.204	27.323	27.441	27.559	27.677	27.796	27.914
23	28.032	28.150	28.268	28.386	28.504	28.622	28.740	28.858	28.976	29.093
24	29.210	29.328	29.446	29.563	29.681	29.799	29.917	30.035	30.152	30.270
25	30.388	30.505	30.622	30.739	30.855	30.972	31.089	31.205	31.322	31.438
26	31.555	31.672	31.788	31.905	32.021	32.138	32.254	32.370	32.487	32.603
27	32.719	32.835	32.951	33.068	33.184	33.300	33.416	33.532	33.647	33.763
28	33.879	33.995	34.111	34.227	34.342	34.458	34.573	34.688	34.803	34.918
29	35.033	35.148	35.263	35.378	35.493	35.608	35.723	35.838	35.952	36.066
30	36.181	36.296	36.410	36.524	36.639	36.753	36.867	36.981	37.095	37.209
31	37.323	37.437	37.551	37.664	37.778	37.892	38.005	38.119	38.232	38.346
32	38.459	38.572	38.686	38.799	38.912	39.025	39.138	39.251	39.364	39.477
33	39.590	39.703	39.816	39.928	40.041	40.154	40.266	40.379	40.492	40.604
34	40.716	40.828	40.940	41.052	41.163	41.275	41.386	41.498	41.609	41.721
35	41.832	41.943	42.055	42.166	42.277	42.389	42.500	42.611	42.722	42.833
36	42.944	43.055	43.165	43.276	43.387	43.498	43.608	43.719	43.829	43.939
37	44.050	44.160	44.270	44.381	44.490	44.600	44.710	44.820	44.930	45.039
38	45.149	45.259	45.368	45.478	45.587	45.696	45.806	45.915	46.024	46.133
39	46.242	46.351	46.460	46.569	46.678	46.786	46.895	47.003	47.112	47.220
40	47.328	47.436	47.544	47.652	47.760	47.868	47.976	48.084	48.192	48.299
41	48.407	48.515	48.622	48.730	48.837	48.945	49.052	49.159	49.266	49.373
42	49.480	49.587	49.694	49.801	49.907	50.014	50.120	50.226	50.333	50.439
43	50.545	50.651	50.757	50.864	50.970	51.076	51.182	51.288	51.394	51.499
44	51.605	51.711	51.816	51.922	52.027	52.132	52.238	52.343	52.448	52.553
45	52.658	52.763	52.868	52.973	53.078	53.182	53.287	53.392	53.496	53.601
46	53.705	53.809	53.914	54.018	54.122	54.226	54.330	54.434	54.538	54.642
47	54.746	54.850	54.954	55.057	55.161	55.264	55.368	55.471	55.574	55.677
48	55.780	55.883	55.986	56.089	56.192	56.295	56.398	56.500	56.603	56.706
49	56.808	56.910	57.013	57.116	57.218	57.320	57.422	57.522	57.626	57.728
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743

TABLE 6.—Percentages by Volume at 60° F, Corresponding to Various Percentages by Weight in Mixtures of Ethyl Alcohol and Water—Continued

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743
51	58.844	58.945	59.046	59.147	59.248	59.349	59.450	59.550	59.651	59.752
52	59.852	59.952	60.053	60.154	60.254	60.354	60.454	60.554	60.654	60.754
53	60.854	60.954	61.054	61.154	61.254	61.353	61.453	61.552	61.652	61.751
54	61.850	61.949	62.048	62.147	62.246	62.344	62.443	62.542	62.640	62.738
55	62.837	62.936	63.034	63.132	63.231	63.329	63.427	63.526	63.624	63.722
56	63.820	63.918	64.016	64.114	64.212	64.310	64.408	64.505	64.603	64.701
57	64.798	64.895	64.993	65.090	65.188	65.285	65.382	65.479	65.575	65.672
58	65.768	65.865	65.961	66.058	66.154	66.251	66.347	66.444	66.540	66.636
59	66.732	66.828	66.924	67.020	67.116	67.212	67.308	67.404	67.499	67.595
60	67.690	67.785	67.881	67.976	68.071	68.166	68.261	68.356	68.451	68.546
61	68.641	68.736	68.831	68.925	69.020	69.115	69.209	69.304	69.398	69.492
62	69.586	69.680	69.774	69.868	69.962	70.056	70.149	70.243	70.336	70.430
63	70.523	70.616	70.710	70.803	70.897	70.990	71.083	71.176	71.269	71.362
64	71.455	71.548	71.641	71.733	71.826	71.918	72.011	72.103	72.196	72.288
65	72.380	72.472	72.564	72.656	72.748	72.840	72.932	73.024	73.116	73.207
66	73.299	73.391	73.482	73.574	73.665	73.756	73.847	73.938	74.029	74.120
67	74.211	74.302	74.393	74.484	74.575	74.665	74.756	74.846	74.937	75.027
68	75.117	75.207	75.297	75.387	75.477	75.567	75.657	75.747	75.837	75.926
69	76.016	76.106	76.195	76.285	76.374	76.464	76.553	76.642	76.731	76.820
70	76.909	76.998	77.087	77.176	77.264	77.353	77.441	77.529	77.618	77.706
71	77.794	77.882	77.970	78.058	78.146	78.234	78.322	78.410	78.497	78.584
72	78.672	78.760	78.847	78.934	79.022	79.109	79.196	79.283	79.370	79.457
73	79.544	79.631	79.718	79.805	79.892	79.978	80.065	80.151	80.238	80.324
74	80.410	80.496	80.582	80.668	80.754	80.840	80.926	81.012	81.098	81.183
75	81.269	81.355	81.440	81.526	81.611	81.696	81.781	81.866	81.951	82.036
76	82.121	82.206	82.291	82.376	82.461	82.545	82.630	82.714	82.799	82.883
77	82.967	83.051	83.135	83.219	83.303	83.387	83.471	83.555	83.638	83.722
78	83.805	83.888	83.972	84.055	84.138	84.221	84.304	84.387	84.470	84.553
79	84.636	84.719	84.801	84.884	84.966	85.049	85.131	85.213	85.295	85.377
80	85.459	85.541	85.623	85.705	85.787	85.868	85.950	86.031	86.113	86.194
81	86.275	86.356	86.437	86.518	86.599	86.680	86.761	86.842	86.922	87.002
82	87.083	87.164	87.244	87.324	87.405	87.485	87.565	87.645	87.725	87.805
83	87.885	87.965	88.045	88.124	88.204	88.283	88.362	88.441	88.520	88.599
84	88.678	88.757	88.836	88.915	88.994	89.072	89.151	89.229	89.308	89.386
85	89.464	89.542	89.620	89.698	89.776	89.854	89.932	90.009	90.086	90.163
86	90.240	90.317	90.394	90.471	90.548	90.625	90.702	90.779	90.855	90.932
87	91.008	91.084	91.161	91.237	91.313	91.388	91.464	91.540	91.615	91.691
88	91.766	91.841	91.917	91.992	92.068	92.143	92.218	92.293	92.367	92.442
89	92.517	92.591	92.666	92.740	92.814	92.888	92.962	93.035	93.108	93.181
90	93.254	93.327	93.400	93.473	93.546	93.619	93.692	93.764	93.837	93.910
91	93.982	94.054	94.126	94.198	94.270	94.342	94.414	94.486	94.557	94.629
92	94.700	94.771	94.842	94.913	94.984	95.055	95.126	95.196	95.267	95.337
93	95.407	95.477	95.547	95.617	95.687	95.757	95.826	95.896	95.965	96.034
94	96.103	96.172	96.241	96.310	96.378	96.447	96.515	96.583	96.652	96.720
95	96.787	96.855	96.922	96.990	97.057	97.125	97.192	97.259	97.326	97.392
96	97.459	97.526	97.592	97.658	97.724	97.790	97.856	97.921	97.987	98.052
97	98.117	98.182	98.247	98.312	98.376	98.440	98.505	98.569	98.633	98.696
98	98.759	98.822	98.886	98.949	99.012	99.075	99.137	99.200	99.262	99.324
99	99.386	99.448	99.510	99.572	99.633	99.695	99.756	99.817	99.878	99.939
100	100.000									

TABLE 7.—Percentages by Weight, Corresponding to Various Percentages by Volume at 60° F in Mixtures of Ethyl Alcohol and Water

Per Cent Alcohol by Volume at 60° F	Per Cent Alcohol by Weight	Differences	Per Cent Alcohol by Volume at 60° F	Per Cent Alcohol by Weight	Differences
0	0.000		50	42.487	
1	0.795	0.795	51	43.428	0.941
2	1.593	.798	52	44.374	.946
3	2.392	.799	53	45.326	.952
4	3.194	.802	54	46.283	.957
		.804			.962
5	3.998		55	47.245	
6	4.804	.806	56	48.214	.969
7	5.612	.808	57	49.187	.973
8	6.422	.810	58	50.167	.980
9	7.234	.812	59	51.154	.987
		.813			.993
10	8.047		60	52.147	
11	8.862	.815	61	53.146	.999
12	9.679	.817	62	54.152	1.006
13	10.497	.818	63	55.165	1.013
14	11.317	.820	64	56.184	1.019
		.821			1.024
15	12.138		65	57.208	
16	12.961	.823	66	58.241	1.033
17	13.786	.825	67	59.279	1.038
18	14.612	.826	68	60.325	1.046
19	15.440	.828	69	61.379	1.054
		.829			1.062
20	16.269		70	62.441	
21	17.100	.831	71	63.511	1.070
22	17.933	.833	72	64.588	1.077
23	18.768	.835	73	65.674	1.086
24	19.604	.836	74	66.768	1.094
		.839			1.102
25	20.443		75	67.870	
26	21.285	.842	76	68.982	1.112
27	22.127	.842	77	70.102	1.120
28	22.973	.846	78	71.234	1.132
29	23.820	.847	79	72.375	1.141
		.850			1.151
30	24.670		80	73.526	
31	25.524	.854	81	74.686	1.160
32	26.382	.858	82	75.858	1.172
33	27.242	.860	83	77.039	1.181
34	28.104	.862	84	78.233	1.194
		.867			1.208
35	28.971		85	79.441	
36	29.842	.871	86	80.662	1.221
37	30.717	.875	87	81.897	1.235
38	31.596	.879	88	83.144	1.247
39	32.478	.882	89	84.408	1.264
		.886			1.281
40	33.364		90	85.689	
41	34.254	.890	91	86.989	1.300
42	35.150	.896	92	88.310	1.321
43	36.050	.900	93	89.652	1.342
44	36.955	.905	94	91.025	1.373
		.910			1.398
45	37.865		95	92.423	
46	38.778	.913	96	93.851	1.428
47	39.697	.919	97	95.315	1.464
48	40.622	.925	98	96.820	1.505
49	41.551	.929	99	98.381	1.561
		.936			1.619
50	42.487		100	100.000	

TABLE 8.—Temperature Corrections to Readings of Alcoholometers (Standard at 20° C)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which tables 2, 3, 4, 5, 6, and 7 are calculated. The hydrometer is assumed to be of Jena 16^{III} glass]

Observed Tempera- ture in Degrees Centigrade	Observed Per Cent Alcohol by Weight																				
	Add to Observed Per Cent Alcohol																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
10	0.67	0.91	1.47	2.43	3.18	3.55	3.59	3.55	3.49	3.47	3.45	3.45	3.45	3.45	3.43	3.42	3.36	3.26	3.08	2.86	
11			1.35	2.20	2.84	3.19	3.24	3.20	3.14	3.11	3.10	3.10	3.10	3.10	3.09	3.08	3.03	2.93	2.78	2.58	
12				1.96	2.51	2.83	2.88	2.85	2.79	2.77	2.76	2.76	2.76	2.76	2.75	2.73	2.68	2.50	2.48	2.31	
13					2.19	2.47	2.52	2.52	2.44	2.42	2.42	2.42	2.42	2.42	2.41	2.39	2.36	2.20	2.18	2.03	
14						1.86	2.11	2.16	2.15	2.10	2.08	2.07	2.07	2.07	2.06	2.05	2.03	1.98	1.88	1.75	
15							1.76	1.79	1.78	1.75	1.73	1.73	1.73	1.73	1.72	1.71	1.69	1.65	1.57	1.46	
16								1.44	1.43	1.41	1.39	1.38	1.38	1.38	1.37	1.36	1.35	1.32	1.26	1.17	
17									1.08	1.06	1.04	1.04	1.04	1.04	1.03	1.02	1.01	.99	.95	.89	
18										.71	.72	.72	.72	.72	.69	.69	.68	.66	.64	.59	
19											.36	.36	.36	.35	.35	.35	.34	.33	.32	.30	
Subtract from Observed Per Cent Alcohol																					
21		0.13	0.17	0.24	0.29	0.33	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.33	0.32	0.30	0.27	
22			.26	.34	.48	.59	.70	.70	.70	.70	.70	.70	.70	.70	.69	.69	.66	.64	.60	.54	
23				.52	.73	.90	1.06	1.06	1.05	1.04	1.04	1.04	1.04	1.04	1.03	1.02	1.00	.97	.90	.81	
24						.76	1.41	1.41	1.40	1.39	1.39	1.39	1.39	1.39	1.38	1.36	1.35	1.29	1.20	1.09	
25							.77	.77	.76	.74	1.74	1.74	1.74	1.74	1.74	1.73	1.68	1.62	1.51	1.36	
26								2.12	2.11	2.10	2.10	2.10	2.10	2.10	2.09	2.09	2.06	2.02	1.95	1.82	
27									2.46	2.45	2.45	2.45	2.45	2.45	2.44	2.42	2.40	2.37	2.28	2.13	
28									2.81	2.82	2.82	2.80	2.80	2.80	2.79	2.75	2.71	2.61	2.45	2.21	
29										3.17	3.16	3.15	3.15	3.15	3.14	3.13	3.06	2.94	2.76	2.49	
30											3.54	3.52	3.50	3.50	3.49	3.46	3.41	3.27	3.08	2.78	
31												3.89	3.87	3.86	3.86	3.84	3.82	3.75	3.61	3.40	
32													4.24	4.22	4.22	4.19	4.17	4.10	3.95	3.72	
33														4.58	4.58	4.57	4.55	4.45	4.29	4.04	
34															4.93	4.92	4.91	4.89	4.80	4.63	
35																5.27	5.26	5.15	4.98	4.69	
36																	5.63	5.50	5.32	5.02	
37																		5.95	5.85	5.67	
38																			6.21	6.02	
39																				6.37	
40																					

TABLE 9.—Density at 15° C of Mixtures (by weight) of Methyl Alcohol and Water

[Calculated from the specific gravity determinations of Doroshovskii and Rozhdstvenskii at $\frac{15^\circ}{15^\circ}$ C¹]

Per Cent Methyl Alcohol by Weight	D $\frac{15^\circ}{4^\circ}$ C	Differences	Per Cent Methyl Alcohol by Weight	D $\frac{15^\circ}{4^\circ}$ C	Differences
0	0.99913		50	0.91852	
1	.99727	0.00186	51	.91653	0.00199
2	.99543	184	52	.91451	202
3	.99370	173	53	.91248	203
4	.99198	172	54	.91044	204
		169			205
5	.99029	165	55	.90839	208
6	.98864	163	56	.90631	210
7	.98701	154	57	.90421	211
8	.98547	153	58	.90210	214
9	.98394	153	59	.89996	215
10	.98241	148	60	.89781	218
11	.98093	148	61	.89563	222
12	.97945	143	62	.89341	224
13	.97802	142	63	.89117	227
14	.97660	142	64	.88890	228
15	.97518	141	65	.88662	229
16	.97377	140	66	.88433	230
17	.97237	141	67	.88203	232
18	.97096	141	68	.87971	232
19	.96955	141	69	.87739	232
20	.96814	141	70	.87507	236
21	.96673	140	71	.87271	238
22	.96533	141	72	.87033	241
23	.96392	141	73	.86792	246
24	.96251	143	74	.86546	246
25	.96108	145	75	.86300	249
26	.95963	146	76	.86051	250
27	.95817	149	77	.85801	250
28	.95668	150	78	.85551	251
29	.95518	152	79	.85300	252
30	.95366	153	80	.85048	254
31	.95213	157	81	.84794	258
32	.95056	160	82	.84536	262
33	.94896	162	83	.84274	265
34	.94734	164	84	.84009	267
35	.94570	166	85	.83742	267
36	.94404	167	86	.83475	268
37	.94237	170	87	.83207	270
38	.94067	173	88	.82937	270
39	.93894	174	89	.82667	271
40	.93720	177	90	.82396	272
41	.93543	178	91	.82124	275
42	.93365	180	92	.81849	281
43	.93185	184	93	.81568	283
44	.93001	186	94	.81285	286
45	.92815	188	95	.80999	286
46	.92627	191	96	.80713	285
47	.92436	194	97	.80428	285
48	.92242	194	98	.80143	284
49	.92048	196	99	.79859	282
50	.91852		100	.79577	

¹ J. Russ., Phys. Chem. Soc., 41, pp. 977-996; 1909.

TABLE 10.—Specific Gravity at 15°
 15° C of Mixtures (by Volume) of Methyl
Alcohol and Water

[Calculated from the same data as Table 9]

Per Cent Methyl Alcohol by Vol- ume at 15 C	D 15° 15° C	Differences	Per Cent Methyl Alcohol by Vol- ume at 15 C	D 15° 15° C	Differences
0	1.00000		50	0.93326	
1	.99851	0.00149	51	.93155	0.00171
2	.99703	148	52	.92982	173
3	.99560	143	53	.92806	176
4	.99422	138	54	.92626	180
		139			183
5	.99283		55	.92443	
6	.99146	137	56	.92256	187
7	.99011	135	57	.92067	189
8	.98877	134	58	.91877	190
9	.98746	131	59	.91682	195
		125			199
10	.98621		60	.91483	
11	.98496	125	61	.91282	201
12	.98370	126	62	.91079	203
13	.98247	123	63	.90873	206
14	.98125	122	64	.90663	210
		122			213
15	.98003		65	.90450	
16	.97884	119	66	.90234	216
17	.97766	118	67	.90014	220
18	.97648	118	68	.89790	224
19	.97530	118	69	.89561	229
		117			234
20	.97413		70	.89327	
21	.97295	118	71	.89088	239
22	.97177	118	72	.88844	244
23	.97058	119	73	.88596	248
24	.96939	119	74	.88346	250
		119			254
25	.96820		75	.88092	
26	.96700	120	76	.87836	256
27	.96580	120	77	.87578	258
28	.96459	121	78	.87312	266
29	.96338	121	79	.87040	272
		122			280
30	.96216		80	.86760	
31	.96091	125	81	.86474	286
32	.95966	125	82	.86180	294
33	.95838	128	83	.85883	297
34	.95708	130	84	.85582	301
		132			306
35	.95576		85	.85276	
36	.95443	133	86	.84967	309
37	.95308	135	87	.84646	321
38	.95170	138	88	.84314	332
39	.95029	141	89	.83971	343
		143			348
40	.94886		90	.83623	
41	.94741	145	91	.83269	354
42	.94593	148	92	.82907	362
43	.94443	150	93	.82538	369
44	.94291	152	94	.82163	375
		155			391
45	.94136		95	.81772	
46	.93979	157	96	.81363	409
47	.93820	159	97	.80942	421
48	.93657	163	98	.80514	428
49	.93493	164	99	.80082	432
		167			435
50	.93326		100	.79647	

TABLE 11.—Percentages by Volume at 15° C, Corresponding to Various Percentages by Weight in Mixtures of Methyl Alcohol and Water

Per Cent by Weight	Per Cent by Volume at 15° C	Differences	Per Cent by Weight	Per Cent by Volume at 15° C	Differences
0	0.000		50	57.712	
1	1.253	1.253	51	58.739	1.027
2	2.502	1.249	52	59.759	1.020
3	3.746	1.244	53	60.773	1.014
4	4.986	1.240	54	61.781	1.008
		1.236			1.002
5	6.222		55	62.783	
6	7.454	1.232	56	63.778	.995
7	8.682	1.228	57	64.767	.989
8	9.907	1.225	58	65.750	.983
9	11.128	1.221	59	66.725	.975
		1.217			.968
10	12.345		60	67.693	
11	13.559	1.214	61	68.654	.961
12	14.770	1.211	62	69.607	.953
13	15.977	1.207	63	70.552	.945
14	17.181	1.204	64	71.490	.938
		1.201			.930
15	18.382		65	72.420	
16	19.579	1.197	66	73.344	.924
17	20.773	1.194	67	74.262	.918
18	21.963	1.190	68	75.172	.910
19	23.149	1.186	69	76.077	.905
		1.183			.899
20	24.332		70	76.976	
21	25.512	1.180	71	77.864	.888
22	26.688	1.176	72	78.746	.882
23	27.860	1.172	73	79.618	.872
24	29.029	1.169	74	80.480	.862
		1.164			.856
25	30.193		75	81.336	
26	31.354	1.161	76	82.182	.846
27	32.510	1.156	77	83.022	.840
28	33.662	1.152	78	83.855	.833
29	34.809	1.147	79	84.680	.825
		1.143			.815
30	35.952		80	85.499	
31	37.091	1.139	81	86.310	.811
32	38.224	1.133	82	87.110	.800
33	39.352	1.128	83	87.899	.789
34	40.476	1.124	84	88.677	.778
		1.118			.771
35	41.594		85	89.448	
36	42.708	1.114	86	90.212	.764
37	43.816	1.108	87	90.968	.756
38	44.919	1.103	88	91.716	.748
39	46.016	1.097	89	92.456	.740
		1.093			.732
40	47.109		90	93.188	
41	48.195	1.086	91	93.912	.724
42	49.277	1.082	92	94.627	.715
43	50.353	1.076	93	95.326	.699
44	51.422	1.069	94	96.017	.691
		1.064			.680
45	52.486		95	96.697	
46	53.544	1.058	96	97.370	.673
47	54.595	1.051	97	98.036	.666
48	55.639	1.044	98	98.696	.660
49	56.678	1.039	99	99.351	.655
		1.034			.649
50	57.712		100	100.000	

TABLE 12.—Temperature Corrections to Readings of Saccharometers (Standard at 20° C)

[This table is calculated using the data on thermal expansion of sugar solutions by Plato⁴, assuming the instrument to be of Jena 16^{III} glass. The table should be used with caution and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Temperature in Degrees Centigrade	Observed Per Cent of Sugar													
	0	5	10	15	20	25	30	35	40	45	50	55	60	70
	Subtract from Observed Per cent													
0	0.30	0.49	0.65	0.77	0.89	0.99	1.08	1.16	1.24	1.31	1.37	1.41	1.44	1.49
5	.36	.47	.56	.65	.73	.80	.86	.91	.97	1.01	1.05	1.08	1.10	1.14
10	.32	.38	.43	.48	.52	.57	.60	.64	.67	.70	.72	.74	.75	.77
11	.31	.35	.40	.44	.48	.51	.55	.58	.60	.63	.65	.66	.68	.70
12	.29	.32	.36	.40	.43	.46	.50	.52	.54	.56	.58	.59	.60	.62
13	.26	.29	.32	.35	.38	.41	.44	.46	.48	.49	.51	.52	.53	.55
14	.24	.26	.29	.31	.34	.36	.38	.40	.41	.42	.44	.45	.46	.47
15	.20	.22	.24	.26	.28	.30	.32	.33	.34	.36	.36	.37	.38	.39
16	.17	.18	.20	.22	.23	.25	.26	.27	.28	.28	.29	.30	.31	.32
17	.13	.14	.15	.16	.18	.19	.20	.20	.21	.21	.22	.23	.23	.24
18	.09	.10	.10	.11	.12	.13	.13	.14	.14	.14	.15	.15	.15	.16
19	.05	.05	.05	.06	.06	.06	.07	.07	.07	.07	.08	.08	.08	.08
17.5	.11	.12	.12	.14	.15	.16	.16	.17	.17	.18	.18	.19	.19	.20
15.56 (60° F)	.18	.20	.22	.24	.26	.28	.29	.30	.30	.32	.33	.33	.34	.34
	Add to Observed Per Cent													
	21	22	23	24	25	26	27	28	29	30	35	40	45	50
	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09
21	.04	.10	.11	.12	.12	.13	.14	.14	.15	.15	.16	.16	.16	.16
22	.10	.16	.17	.17	.19	.20	.21	.21	.22	.23	.24	.24	.24	.24
23	.16	.22	.23	.24	.26	.27	.28	.29	.30	.31	.32	.32	.32	.32
24	.21	.28	.30	.31	.32	.34	.35	.36	.38	.38	.39	.39	.40	.39
25	.27	.33	.34	.36	.37	.40	.42	.44	.46	.47	.47	.48	.48	.48
26	.33	.40	.41	.42	.44	.46	.48	.50	.52	.54	.55	.56	.56	.56
27	.40	.46	.47	.49	.51	.54	.56	.58	.60	.61	.62	.63	.64	.64
28	.46	.54	.55	.56	.59	.61	.63	.66	.68	.70	.71	.72	.72	.72
29	.54	.61	.62	.63	.66	.68	.71	.73	.76	.78	.79	.80	.80	.81
30	.61	.62	.63	.66	.68	.71	.73	.76	.78	.79	.80	.80	.80	.81
35	.99	1.01	1.02	1.06	1.10	1.13	1.16	1.18	1.20	1.21	1.22	1.22	1.23	1.22
40	1.42	1.45	1.47	1.51	1.54	1.57	1.60	1.62	1.64	1.65	1.65	1.65	1.66	1.65
45	1.91	1.94	1.96	2.00	2.03	2.05	2.07	2.09	2.10	2.10	2.10	2.10	2.10	2.08
50	2.46	2.48	2.50	2.53	2.56	2.57	2.58	2.59	2.59	2.58	2.58	2.57	2.56	2.52
55	3.05	3.07	3.09	3.12	3.12	3.12	3.12	3.11	3.10	3.08	3.07	3.05	3.03	2.97
60	3.69	3.72	3.73	3.73	3.72	3.70	3.67	3.65	3.62	3.60	3.57	3.54	3.50	3.43
27.5	0.43	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.58	0.59	0.60	0.60	0.60

⁴ Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 140; 1900.

TABLE 13.—Density^a of Solutions of Cane Sugar at 20° C

[This table is the basis for standardizing hydrometers indicating per cent of sugar at 20° C]

Per Cent Sugar	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051933	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055325	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095782	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106786	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114231	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166269	1.166775	1.167281	1.167786	1.168293	1.168800	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532

^a According to Dr. F. Plato (Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 153; 1900).

TABLE 13.—Density of Solutions of Cane Sugar at 20° C.—Continued

Per Cent Sugar	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246234	1.246795	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273035	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295910	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300079	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306069	1.306671	1.307271	1.307872	1.308473	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312699	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335342	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342798	1.343421	1.344046	1.344671	1.345296	1.345922	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353456	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363590	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378326
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.402452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408398	1.409061	1.409723	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422390	1.423059	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460495	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275
90	1.479976	1.480677	1.481378	1.482080	1.482782	1.483484	1.484187	1.484890	1.485593	1.486297
91	1.487002	1.487707	1.488411	1.489117	1.489823	1.490528	1.491234	1.491941	1.492647	1.493355
92	1.494063	1.494771	1.495479	1.496188	1.496897	1.497606	1.498316	1.499026	1.499736	1.500447
93	1.501158	1.501870	1.502582	1.503293	1.504006	1.504719	1.505432	1.506146	1.506859	1.507574
94	1.508289	1.509004	1.509720	1.510435	1.511151	1.511868	1.512585	1.513302	1.514019	1.514737
95	1.515455	1.516174	1.516893	1.517612	1.518332	1.519051	1.519771	1.520492	1.521212	1.521934
96	1.522656	1.523378	1.524100	1.524823	1.525546	1.526269	1.526993	1.527717	1.528441	1.529166
97	1.529891	1.530616	1.531342	1.532068	1.532794	1.533521	1.534248	1.534976	1.535704	1.536432
98	1.537161	1.537889	1.538618	1.539347	1.540076	1.540806	1.541536	1.542267	1.542998	1.543730
99	1.544462	1.545194	1.545926	1.546659	1.547392	1.548127	1.548861	1.549595	1.550329	1.551064
100	1.551800									

TABLE 14.—Density of Solutions of Sulphuric Acid (H_2SO_4) at 20°C [Calculated from Dr. J. Domke's table.* Adopted as the basis for standardization of hydrometers indicating per cent of sulphuric acid at 20°C]

Per Cent H_2SO_4	$D_{40}^{20} \text{C}$	Per Cent H_2SO_4	$D_{40}^{20} \text{C}$	Per Cent H_2SO_4	$D_{40}^{20} \text{C}$
0	0.99823	50	1.39505	91.0	1.81950
1	1.00506	51	1.40487	91.2	1.82045
2	1.01178	52	1.41481	91.4	1.82137
3	1.01839	53	1.42487	91.6	1.82227
4	1.02500	54	1.43503	91.8	1.82315
5	1.03168	55	1.44530	92.0	1.82401
6	1.03843	56	1.45568	92.2	1.82484
7	1.04527	57	1.46615	92.4	1.82564
8	1.05216	58	1.47673	92.6	1.82641
9	1.05909	59	1.48740	92.8	1.82717
10	1.06609	60	1.49818	93.0	1.82790
11	1.07314	61	1.50904	93.2	1.82860
12	1.08026	62	1.51999	93.4	1.82928
13	1.08744	63	1.53102	93.6	1.82993
14	1.09468	64	1.54213	93.8	1.83055
15	1.10199	65	1.55333	94.0	1.83115
16	1.10936	66	1.56460	94.2	1.83172
17	1.11679	67	1.57595	94.4	1.83226
18	1.12428	68	1.58739	94.6	1.83276
19	1.13183	69	1.59890	94.8	1.83324
20	1.13943	70	1.61048	95.0	1.83368
21	1.14709	71	1.62213	95.1	1.83399
22	1.15480	72	1.63384	95.2	1.83410
23	1.16258	73	1.64560	95.3	1.83430
24	1.17041	74	1.65738	95.4	1.83449
25	1.17830	75	1.66917	95.5	1.83469
26	1.18624	76	1.68095	95.6	1.83486
27	1.19423	77	1.69268	95.7	1.83503
28	1.20227	78	1.70433	95.8	1.83520
29	1.21036	79	1.71585	95.9	1.83534
30	1.21850	80	1.72717	96.0	1.83548
31	1.22669	81	1.73827	96.1	1.83560
32	1.23492	82	1.74904	96.2	1.83572
33	1.24320	83	1.75943	96.3	1.83584
34	1.25154	84	1.76932	96.4	1.83594
35	1.25992	85	1.77860	96.5	1.83604
36	1.26836	85.5	1.78300	96.6	1.83613
37	1.27685	86	1.78721	96.7	1.83621
38	1.28543	86.5	1.79124	96.8	1.83628
39	1.29407	87	1.79509	96.9	1.83634
40	1.30278	87.5	1.79875	97.0	1.83637
41	1.31157	88	1.80223	97.1	1.83639
42	1.32043	88.5	1.80552	97.2	1.83640
43	1.32938	89	1.80864	97.3	1.83640
44	1.33843	89.5	1.81159	97.4	1.83639
45	1.34759	90	1.81438	97.5	1.83637
46	1.35686	90.2	1.81545	97.6	1.83634
47	1.36625	90.4	1.81650	97.7	1.83629
48	1.37574	90.6	1.81753	97.8	1.83623
49	1.38533	90.8	1.81853	97.9	1.83615
50	1.39505	91.0	1.81950	98.0	1.83605

* Wiss. Abh. der Kaiserlichen Normal-Messungs-Kommission, 5, p. 131; 1900.

TABLE 15.—Temperature Corrections to Per Cent of Sulphuric Acid Determined by Hydrometer (Standard at 20° C)

[Calculated from the same data as the preceding table, assuming Jena 16^{III} glass as the material used. The table should be used with caution, and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Observed Per Cent H ₂ SO ₄	Temperature in Degrees Centigrade											
	0	5	10	15	25	30	35	40	45	50	55	60
	Subtract from Observed Per Cent				Add to Observed Per Cent							
0					0.16	0.35	0.59	0.86	1.17	1.5	1.9	2.1
5	0.59	0.49	0.36	0.20	0.24	0.50	0.79	1.11	1.45	1.8	2.2	2.6
10	0.92	0.72	0.51	0.27	0.29	0.60	0.93	1.28	1.65	2.0	2.4	2.8
20	1.39	1.06	0.72	0.36	0.37	0.75	1.14	1.53	1.93	2.3	2.7	3.1
30	1.64	1.23	0.82	0.41	0.41	0.82	1.24	1.65	2.07	2.5	2.9	3.3
40	1.65	1.24	0.82	0.41	0.41	0.82	1.22	1.62	2.03	2.4	2.8	3.2
50	1.56	1.17	0.78	0.39	0.38	0.77	1.15	1.52	1.90	2.3	2.6	3.0
60	1.52	1.14	0.76	0.38	0.37	0.74	1.11	1.48	1.84	2.2	2.6	2.9
70	1.54	1.15	0.76	0.38	0.38	0.75	1.13	1.50	1.86	2.2	2.6	3.0
80	1.72	1.30	0.87	0.44	0.45	0.90	1.36	1.83	2.31	2.8	3.3	3.8
81	1.76	1.34	0.92	0.44	0.47	0.93	1.42	1.93	2.44	3.0	3.5	4.0
82	1.84	1.41	0.96	0.47	0.50	1.00	1.51	2.04	2.58	3.1	3.7	4.3
83	1.94	1.48	1.00	0.50	0.53	1.06	1.59	2.18	2.78	3.4	4.0	4.6
84	2.05	1.57	1.06	0.53	0.55	1.12	1.74	2.36	3.0	3.7	4.4	5.1
85	2.20	1.67	1.13	0.57	0.61	1.23	1.88	2.57	3.3	4.0	4.9	5.8
86	2.36	1.80	1.22	0.62	0.66	1.35	2.08	2.84	3.7	4.6	5.5	
87	2.54	1.95	1.32	0.67	0.73	1.50	2.31	3.2	4.1	5.2		
88	2.75	2.12	1.44	0.74	0.81	1.67	2.59	3.6	4.7	6.0		
89	3.01	2.31	1.58	0.82	0.89	1.86	2.91	4.1	5.6			
90	3.27	2.53	1.73	0.91	0.99	2.10	3.4	4.9				
91	3.57	2.78	1.93	1.01	1.13	2.44	4.1					
92	3.91	3.06	2.13	1.12	1.32	3.00						
93	4.29	3.38	2.37	1.26	1.64							
94	4.75	3.77	2.69	1.46								
95	5.29	4.26	3.12	1.76								
96	5.96	4.88	3.65	2.19								
97	6.78	5.68	4.42	2.90								

TABLE 16.—Degrees Baumé Corresponding to Specific Gravities at 60° F ($15^{\circ}56$ C)
Greater than 1

[Calculated from the formula degrees Baumé = $145 - \frac{145}{D_{60^{\circ}\text{F}}}$ which defines the Baumé scale, in general use in the United States, for liquids heavier than water]

$D_{15^{\circ}56\text{C}}$	0	1	2	3	4	5	6	7	8	9	Diff.
1.00	0.000	0.145	0.289	0.434	0.578	0.721	0.865	1.008	1.151	1.293	143
1.01	1.436	1.578	1.719	1.861	2.002	2.143	2.283	2.424	2.564	2.704	141
1.02	2.843	2.982	3.121	3.260	3.399	3.537	3.675	3.812	3.950	4.087	138
1.03	4.223	4.360	4.496	4.632	4.768	4.903	5.038	5.174	5.308	5.443	136
1.04	5.577	5.711	5.845	5.978	6.111	6.244	6.377	6.509	6.641	6.773	133
1.05	6.905	7.036	7.167	7.298	7.429	7.559	7.689	7.819	7.949	8.078	130
1.06	8.208	8.336	8.465	8.594	8.722	8.850	8.978	9.105	9.232	9.359	128
1.07	9.486	9.613	9.739	9.865	9.991	10.116	10.242	10.367	10.492	10.616	126
1.08	10.741	10.865	10.989	11.113	11.236	11.359	11.483	11.605	11.728	11.850	124
1.09	11.972	12.094	12.216	12.338	12.459	12.580	12.701	12.821	12.942	13.062	121
1.10	13.182	13.302	13.421	13.540	13.659	13.778	13.897	14.015	14.134	14.252	119
1.11	14.370	14.487	14.604	14.721	14.838	14.955	15.072	15.188	15.304	15.420	117
1.12	15.536	15.651	15.767	15.882	15.997	16.111	16.226	16.340	16.454	16.568	115
1.13	16.682	16.795	16.908	17.021	17.134	17.247	17.359	17.471	17.583	17.695	113
1.14	17.807	17.919	18.030	18.141	18.252	18.363	18.473	18.583	18.693	18.803	111
1.15	18.913	19.023	19.132	19.241	19.350	19.459	19.568	19.676	19.784	19.892	109
1.16	20.000	20.108	20.215	20.322	20.430	20.536	20.643	20.750	20.856	20.962	107
1.17	21.068	21.174	21.280	21.385	21.491	21.596	21.701	21.806	21.910	22.014	105
1.18	22.119	22.223	22.327	22.430	22.534	22.637	22.740	22.843	22.946	23.049	103
1.19	23.151	23.254	23.356	23.458	23.560	23.661	23.763	23.864	23.965	24.066	101
1.20	24.167	24.267	24.368	24.468	24.568	24.668	24.768	24.868	24.967	25.066	100
1.21	25.165	25.264	25.363	25.462	25.560	25.658	25.755	25.855	25.952	26.050	98
1.22	26.148	26.245	26.342	26.439	26.536	26.633	26.729	26.826	26.922	27.018	97
1.23	27.114	27.210	27.305	27.401	27.496	27.591	27.686	27.781	27.876	27.970	95
1.24	28.065	28.159	28.253	28.347	28.441	28.534	28.628	28.721	28.814	28.907	94
1.25	29.000	29.093	29.185	29.278	29.370	29.462	29.554	29.646	29.738	29.829	92
1.26	29.921	30.012	30.103	30.194	30.285	30.376	30.466	30.556	30.647	30.737	91
1.27	30.827	30.917	31.006	31.096	31.185	31.275	31.364	31.453	31.542	31.630	89
1.28	31.719	31.807	31.896	31.984	32.072	32.160	32.247	32.335	32.422	32.510	88
1.29	32.597	32.684	32.771	32.858	32.944	33.031	33.117	33.204	33.290	33.376	87
1.30	33.462	33.547	33.633	33.718	33.804	33.889	33.974	34.059	34.144	34.229	85
1.31	34.313	34.397	34.482	34.566	34.650	34.734	34.818	34.901	34.985	35.068	84
1.32	35.152	35.235	35.318	35.401	35.483	35.566	35.649	35.731	35.813	35.895	83
1.33	35.977	36.059	36.141	36.223	36.304	36.386	36.467	36.548	36.629	36.710	81
1.34	36.791	36.872	36.952	37.033	37.113	37.193	37.273	37.353	37.433	37.513	80
1.35	37.593	37.672	37.751	37.831	37.910	37.989	38.068	38.147	38.225	38.304	79
1.36	38.382	38.461	38.539	38.617	38.695	38.773	38.851	38.928	39.006	39.083	78
1.37	39.161	39.238	39.315	39.392	39.469	39.546	39.622	39.699	39.775	39.851	77
1.38	39.928	40.004	40.080	40.156	40.231	40.307	40.382	40.458	40.533	40.608	76
1.39	40.683	40.758	40.833	40.908	40.983	41.057	41.132	41.206	41.280	41.355	75
1.40	41.429	41.503	41.576	41.650	41.724	41.797	41.871	41.944	42.017	42.090	74
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73

TABLE 16.—Degrees Baumé Corresponding to Specific Gravities at $\frac{60^\circ}{60^\circ}$ F ($\frac{15956}{15956}$ C)
Greater than 1—Continued

D $\frac{15956}{15956}$ C	0	1	2	3	4	5	6	7	8	9	Diff.
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73
1.42	42.887	42.959	43.031	43.103	43.174	43.246	43.317	43.388	43.459	43.530	72
1.43	43.601	43.672	43.743	43.814	43.884	43.955	44.025	44.095	44.166	44.236	71
1.44	44.306	44.376	44.445	44.515	44.585	44.654	44.724	44.793	44.862	44.931	70
1.45	45.000	45.069	45.138	45.207	45.275	45.344	45.412	45.481	45.549	45.617	69
1.46	45.685	45.753	45.821	45.889	45.956	46.024	46.091	46.159	46.226	46.293	67
1.47	46.361	46.428	46.495	46.562	46.628	46.695	46.762	46.828	46.894	46.961	67
1.48	47.027	47.093	47.159	47.225	47.291	47.357	47.423	47.488	47.554	47.619	66
1.49	47.685	47.750	47.815	47.880	47.945	48.010	48.075	48.140	48.204	48.269	65
1.50	48.333	48.398	48.462	48.526	48.591	48.655	48.719	48.782	48.846	48.910	64
1.51	48.974	49.037	49.101	49.164	49.227	49.290	49.354	49.417	49.480	49.543	63
1.52	49.605	49.668	49.731	49.793	49.856	49.918	49.980	50.043	50.105	50.167	62
1.53	50.229	50.291	50.353	50.414	50.476	50.538	50.599	50.660	50.722	50.783	61
1.54	50.844	50.905	50.966	51.027	51.088	51.149	51.210	51.270	51.331	51.391	61
1.55	51.452	51.512	51.572	51.632	51.692	51.752	51.812	51.872	51.932	51.992	60
1.56	52.051	52.111	52.170	52.230	52.289	52.348	52.407	52.467	52.526	52.585	59
1.57	52.643	52.702	52.761	52.820	52.878	52.937	52.995	53.053	53.112	53.170	59
1.58	53.228	53.286	53.344	53.402	53.460	53.517	53.575	53.633	53.690	53.748	58
1.59	53.805	53.862	53.920	53.977	54.034	54.091	54.148	54.205	54.262	54.318	57
1.60	54.375	54.432	54.488	54.545	54.601	54.657	54.714	54.770	54.826	54.882	56
1.61	54.938	54.994	55.050	55.106	55.161	55.217	55.272	55.328	55.383	55.439	56
1.62	55.494	55.549	55.604	55.659	55.714	55.769	55.824	55.879	55.934	55.988	55
1.63	56.043	56.098	56.152	56.206	56.261	56.315	56.369	56.423	56.478	56.531	54
1.64	56.585	56.639	56.693	56.747	56.801	56.854	56.908	56.961	57.015	57.068	54
1.65	57.121	57.175	57.228	57.281	57.334	57.387	57.440	57.493	57.545	57.598	53
1.66	57.651	57.703	57.756	57.808	57.861	57.913	57.965	58.017	58.070	58.122	52
1.67	58.174	58.226	58.278	58.329	58.381	58.433	58.485	58.536	58.588	58.639	52
1.68	58.690	58.742	58.793	58.844	58.896	58.947	58.998	59.049	59.100	59.150	51
1.69	59.201	59.252	59.303	59.353	59.404	59.454	59.505	59.555	59.605	59.656	50
1.70	59.706	59.756	59.806	59.856	59.906	59.956	60.006	60.056	60.105	60.155	50
1.71	60.205	60.254	60.304	60.353	60.403	60.452	60.501	60.550	60.600	60.649	49
1.72	60.698	60.747	60.796	60.844	60.893	60.942	60.991	61.039	61.088	61.136	49
1.73	61.185	61.234	61.282	61.330	61.378	61.427	61.475	61.523	61.571	61.619	48
1.74	61.667	61.715	61.762	61.810	61.858	61.906	61.953	62.001	62.048	62.096	48
1.75	62.143	62.190	62.237	62.285	62.332	62.379	62.426	62.473	62.520	62.567	47
1.76	62.614	62.660	62.707	62.754	62.801	62.847	62.894	62.940	62.987	63.033	46
1.77	63.079	63.125	63.172	63.218	63.264	63.310	63.356	63.402	63.448	63.494	46
1.78	63.539	63.585	63.631	63.676	63.722	63.768	63.813	63.858	63.904	63.949	46
1.79	63.994	64.040	64.085	64.130	64.175	64.220	64.265	64.310	64.355	64.400	45
1.80	64.445	64.489	64.534	64.579	64.623	64.668	64.712	64.757	64.801	64.845	45
1.81	64.890	64.934	64.978	65.022	65.066	65.110	65.154	65.198	65.242	65.286	44
1.82	65.330	65.374	65.417	65.461	65.504	65.548	65.591	65.635	65.678	65.722	43
1.83	65.765	65.808	65.852	65.895	65.938	65.981	66.024	66.067	66.110	66.153	43
1.84	66.196	66.238	66.281	66.324	66.367	66.409	66.452	66.494	66.537	66.579	42
1.85	66.622										

TABLE 17.—Specific Gravities at 60°F (15°C) Corresponding to Degrees Baumé for Liquids Heavier than Water[Calculated from the formula specific gravity $60^{\circ}\text{F} = \frac{145}{145 - \text{Deg. Baumé.}}$]

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	1.0007	1.0014	1.0021	1.0028	1.0035	1.0042	1.0049	1.0055	1.0062
1	1.0069	1.0076	1.0083	1.0090	1.0097	1.0105	1.0112	1.0119	1.0126	1.0133
2	1.0140	1.0147	1.0154	1.0161	1.0168	1.0175	1.0183	1.0190	1.0197	1.0204
3	1.0211	1.0218	1.0226	1.0233	1.0240	1.0247	1.0255	1.0262	1.0269	1.0276
4	1.0284	1.0291	1.0298	1.0306	1.0313	1.0320	1.0328	1.0335	1.0342	1.0350
5	1.0357	1.0365	1.0372	1.0379	1.0387	1.0394	1.0402	1.0409	1.0417	1.0424
6	1.0432	1.0439	1.0447	1.0454	1.0462	1.0469	1.0477	1.0484	1.0492	1.0500
7	1.0507	1.0515	1.0522	1.0530	1.0538	1.0545	1.0553	1.0561	1.0569	1.0576
8	1.0584	1.0592	1.0599	1.0607	1.0615	1.0623	1.0630	1.0638	1.0646	1.0654
9	1.0662	1.0670	1.0678	1.0685	1.0693	1.0701	1.0709	1.0717	1.0725	1.0733
10	1.0741	1.0749	1.0757	1.0765	1.0773	1.0781	1.0789	1.0797	1.0805	1.0813
11	1.0821	1.0829	1.0837	1.0845	1.0853	1.0861	1.0870	1.0878	1.0886	1.0894
12	1.0902	1.0910	1.0919	1.0927	1.0935	1.0944	1.0952	1.0960	1.0968	1.0977
13	1.0985	1.0993	1.1002	1.1010	1.1018	1.1027	1.1035	1.1043	1.1052	1.1060
14	1.1069	1.1077	1.1086	1.1094	1.1103	1.1111	1.1120	1.1128	1.1137	1.1145
15	1.1154	1.1162	1.1171	1.1180	1.1188	1.1197	1.1206	1.1214	1.1223	1.1232
16	1.1240	1.1249	1.1258	1.1267	1.1275	1.1284	1.1293	1.1302	1.1310	1.1319
17	1.1328	1.1337	1.1346	1.1355	1.1364	1.1373	1.1381	1.1390	1.1399	1.1408
18	1.1417	1.1426	1.1435	1.1444	1.1453	1.1462	1.1472	1.1481	1.1490	1.1499
19	1.1508	1.1517	1.1526	1.1535	1.1545	1.1554	1.1563	1.1572	1.1581	1.1591
20	1.1600	1.1609	1.1619	1.1628	1.1637	1.1647	1.1656	1.1665	1.1675	1.1684
21	1.1694	1.1703	1.1712	1.1722	1.1731	1.1741	1.1750	1.1760	1.1769	1.1779
22	1.1789	1.1798	1.1808	1.1817	1.1827	1.1837	1.1846	1.1856	1.1866	1.1876
23	1.1885	1.1895	1.1905	1.1915	1.1924	1.1934	1.1944	1.1954	1.1964	1.1974
24	1.1983	1.1993	1.2003	1.2013	1.2023	1.2033	1.2043	1.2053	1.2063	1.2073
25	1.2083	1.2093	1.2104	1.2114	1.2124	1.2134	1.2144	1.2154	1.2164	1.2175
26	1.2185	1.2195	1.2205	1.2216	1.2226	1.2236	1.2247	1.2257	1.2267	1.2278
27	1.2288	1.2299	1.2309	1.2319	1.2330	1.2340	1.2351	1.2361	1.2372	1.2383
28	1.2393	1.2404	1.2414	1.2425	1.2436	1.2447	1.2457	1.2468	1.2478	1.2489
29	1.2500	1.2511	1.2522	1.2532	1.2543	1.2554	1.2565	1.2576	1.2587	1.2598
30	1.2609	1.2620	1.2631	1.2642	1.2653	1.2664	1.2675	1.2686	1.2697	1.2708
31	1.2719	1.2730	1.2742	1.2753	1.2764	1.2775	1.2787	1.2798	1.2809	1.2821
32	1.2832	1.2843	1.2855	1.2866	1.2877	1.2889	1.2900	1.2912	1.2923	1.2935
33	1.2946	1.2958	1.2970	1.2981	1.2993	1.3004	1.3016	1.3028	1.3040	1.3051
34	1.3063	1.3075	1.3087	1.3098	1.3110	1.3122	1.3134	1.3146	1.3158	1.3170
35	1.3182	1.3194	1.3206	1.3218	1.3230	1.3242	1.3254	1.3266	1.3278	1.3291
36	1.3303	1.3315	1.3327	1.3339	1.3352	1.3364	1.3376	1.3389	1.3401	1.3414
37	1.3426	1.3438	1.3451	1.3463	1.3476	1.3488	1.3501	1.3514	1.3526	1.3539
38	1.3551	1.3564	1.3577	1.3590	1.3602	1.3615	1.3628	1.3641	1.3653	1.3666
39	1.3679	1.3692	1.3705	1.3718	1.3731	1.3744	1.3757	1.3770	1.3783	1.3796
40	1.3810	1.3823	1.3836	1.3849	1.3862	1.3876	1.3889	1.3902	1.3916	1.3929
41	1.3942	1.3956	1.3969	1.3983	1.3996	1.4010	1.4023	1.4037	1.4050	1.4064
42	1.4078	1.4091	1.4105	1.4119	1.4133	1.4146	1.4160	1.4174	1.4188	1.4202
43	1.4216	1.4230	1.4244	1.4258	1.4272	1.4286	1.4300	1.4314	1.4328	1.4342
44	1.4356	1.4371	1.4385	1.4399	1.4414	1.4428	1.4442	1.4457	1.4471	1.4486
45	1.4500	1.4515	1.4529	1.4544	1.4558	1.4573	1.4588	1.4602	1.4617	1.4632
46	1.4646	1.4661	1.4676	1.4691	1.4706	1.4721	1.4736	1.4751	1.4766	1.4781
47	1.4796	1.4811	1.4826	1.4841	1.4857	1.4872	1.4887	1.4902	1.4918	1.4933
48	1.4948	1.4964	1.4979	1.4995	1.5010	1.5026	1.5041	1.5057	1.5073	1.5088
49	1.5104	1.5120	1.5136	1.5152	1.5167	1.5183	1.5199	1.5215	1.5231	1.5247
50	1.5263	1.5279	1.5295	1.5312	1.5328	1.5344	1.5360	1.5376	1.5393	1.5409
51	1.5426	1.5442	1.5458	1.5475	1.5491	1.5508	1.5525	1.5541	1.5558	1.5575
52	1.5591	1.5608	1.5625	1.5642	1.5659	1.5676	1.5693	1.5710	1.5727	1.5744
53	1.5761	1.5778	1.5795	1.5812	1.5830	1.5847	1.5865	1.5882	1.5899	1.5917
54	1.5934	1.5952	1.5969	1.5987	1.6004	1.6022	1.6040	1.6058	1.6076	1.6093
55	1.6111	1.6129	1.6147	1.6165	1.6183	1.6201	1.6219	1.6237	1.6256	1.6274
56	1.6292	1.6310	1.6329	1.6347	1.6366	1.6384	1.6403	1.6421	1.6440	1.6459
57	1.6477	1.6496	1.6515	1.6534	1.6553	1.6572	1.6591	1.6610	1.6629	1.6648
58	1.6667	1.6686	1.6705	1.6724	1.6744	1.6763	1.6782	1.6802	1.6821	1.6841
59	1.6860	1.6880	1.6900	1.6919	1.6939	1.6959	1.6979	1.6999	1.7019	1.7039
60	1.7059	1.7079	1.7099	1.7119	1.7139	1.7160	1.7180	1.7200	1.7221	1.7241
61	1.7262	1.7282	1.7303	1.7324	1.7344	1.7365	1.7386	1.7407	1.7428	1.7449
62	1.7470	1.7491	1.7512	1.7533	1.7554	1.7575	1.7597	1.7618	1.7640	1.7661
63	1.7683	1.7705	1.7726	1.7748	1.7770	1.7792	1.7814	1.7836	1.7858	1.7879
64	1.7901	1.7924	1.7946	1.7968	1.7990	1.8012	1.8035	1.8057	1.8080	1.8102
65	1.8125	1.8148	1.8170	1.8193	1.8216	1.8239	1.8262	1.8285	1.8308	1.8331
66	1.8354	1.8378	1.8401	1.8424	1.8448	1.8471	1.8495	1.8519	1.8542	1.8566
67	1.8590	1.8614	1.8638	1.8662	1.8686	1.8710	1.8734	1.8758	1.8782	1.8807
68	1.8831	1.8856	1.8880	1.8905	1.8930	1.8954	1.8979	1.9004	1.9029	1.9054
69	1.9079	1.9104	1.9129	1.9155	1.9180	1.9205	1.9231	1.9256	1.9282	1.9308
70	1.9333									

TABLE 18.—Degrees Baumé Corresponding to Specific Gravities at 60° F $\left(\frac{19956}{15956} C\right)$
Less than 1

[Calculated from the formula degrees Baumé = $\frac{140}{D_{60^{\circ}F}} - 130$ which defines the Baumé scale, in general use in the United States, for liquids lighter than water]

$D_{\frac{19956}{15956}} C$	0	1	2	3	4	5	6	7	8	9	Diff.
.60	103.333	102.945	102.558	102.172	101.788	101.405	101.023	100.642	100.263	99.885	382
.61	99.508	99.133	98.758	98.385	98.013	97.642	97.273	96.904	96.537	96.171	370
.62	95.806	95.443	95.080	94.719	94.359	94.000	93.642	93.285	92.930	92.576	360
.63	92.222	91.870	91.519	91.169	90.820	90.472	90.126	89.780	89.436	89.092	348
.64	88.750	88.409	88.068	87.729	87.391	87.054	86.718	86.383	86.049	85.716	337
.65	85.385	85.054	84.724	84.395	84.067	83.741	83.415	83.090	82.766	82.443	327
.66	82.121	81.800	81.480	81.161	80.843	80.526	80.210	79.895	79.581	79.268	317
.67	78.955	78.644	78.333	78.024	77.715	77.407	77.101	76.795	76.490	76.186	308
.68	75.882	75.580	75.279	74.978	74.678	74.380	74.082	73.785	73.488	73.193	298
.69	72.899	72.605	72.312	72.020	71.729	71.439	71.149	70.861	70.573	70.286	290
.70	70.000	69.715	69.430	69.146	68.864	68.582	68.300	68.020	67.740	67.461	282
.71	67.183	66.906	66.629	66.354	66.078	65.804	65.531	65.258	64.986	64.715	274
.72	64.444	64.175	63.906	63.638	63.370	63.103	62.837	62.572	62.308	62.044	266
.73	61.781	61.518	61.257	60.996	60.736	60.476	60.217	59.959	59.702	59.445	260
.74	59.189	58.934	58.679	58.425	58.172	57.919	57.668	57.416	57.166	56.916	252
.75	56.667	56.418	56.170	55.923	55.676	55.430	55.185	54.941	54.697	54.453	246
.76	54.210	53.968	53.727	53.486	53.246	53.007	52.768	52.529	52.292	52.055	239
.77	51.818	51.582	51.347	51.113	50.879	50.645	50.412	50.180	49.949	49.718	234
.78	49.487	49.257	49.028	48.799	48.571	48.344	48.117	47.891	47.665	47.440	227
.79	47.215	46.991	46.768	46.545	46.322	46.101	45.879	45.659	45.439	45.219	222
.80	45.000	44.781	44.564	44.346	44.129	43.913	43.697	43.482	43.267	43.053	216
.81	42.840	42.626	42.414	42.202	41.990	41.779	41.569	41.359	41.149	40.940	210
.82	40.732	40.524	40.316	40.109	39.903	39.697	39.492	39.287	39.082	38.878	206
.83	38.675	38.472	38.269	38.067	37.866	37.665	37.464	37.264	37.064	36.866	201
.84	36.667	36.469	36.271	36.074	35.877	35.680	35.485	35.289	35.094	34.900	196
.85	34.706	34.512	34.319	34.127	33.934	33.743	33.551	33.361	33.170	32.980	192
.86	32.791	32.602	32.413	32.225	32.037	31.850	31.663	31.476	31.290	31.105	187
.87	30.920	30.735	30.550	30.366	30.183	30.000	29.817	29.635	29.453	29.272	183
.88	29.091	28.910	28.730	28.550	28.371	28.192	28.014	27.835	27.658	27.480	179
.89	27.303	27.127	26.951	26.775	26.600	26.425	26.250	26.076	25.902	25.729	175
.90	25.556	25.383	25.211	25.039	24.867	24.696	24.525	24.355	24.185	24.015	171
.91	23.846	23.677	23.509	23.341	23.173	23.005	22.838	22.672	22.506	22.339	168
.92	22.174	22.009	21.844	21.679	21.515	21.351	21.188	21.025	20.862	20.700	164
.93	20.538	20.376	20.215	20.054	19.893	19.733	19.573	19.413	19.254	19.095	160
.94	18.936	18.778	18.620	18.462	18.305	18.148	17.991	17.835	17.679	17.524	157
.95	17.368	17.214	17.059	16.905	16.751	16.597	16.444	16.290	16.138	15.985	154
.96	15.833	15.682	15.530	15.379	15.228	15.078	14.928	14.778	14.628	14.479	150
.97	14.330	14.181	14.033	13.885	13.737	13.590	13.443	13.297	13.149	13.003	147
.98	12.857	12.712	12.566	12.421	12.276	12.132	11.988	11.844	11.700	11.557	144
.99	11.414	11.271	11.129	10.987	10.845	10.704	10.562	10.421	10.281	10.140	142
1.00	10.000										

TABLE 19.—Specific Gravities at 60° F (15.56° C) Corresponding to Degrees Baumé for Liquids Lighter than Water[Calculated from the formula, Specific Gravity 60° F = $\frac{140}{130 + \text{Deg. B}^{\circ}}$]

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9964	0.9957	0.9950	0.9943	0.9936
11	.9929	.9922	.9915	.9908	.9901	.9894	.9887	.9880	.9873	.9866
12	.9859	.9852	.9845	.9838	.9831	.9825	.9818	.9811	.9804	.9797
13	.9790	.9783	.9777	.9770	.9763	.9756	.9749	.9742	.9736	.9729
14	.9722	.9715	.9709	.9702	.9695	.9689	.9682	.9675	.9669	.9662
15	.9655	.9649	.9642	.9635	.9629	.9622	.9615	.9609	.9602	.9596
16	.9589	.9582	.9576	.9569	.9563	.9556	.9550	.9543	.9537	.9530
17	.9524	.9518	.9511	.9504	.9498	.9492	.9485	.9479	.9472	.9466
18	.9459	.9453	.9447	.9440	.9434	.9428	.9421	.9415	.9409	.9402
19	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346	.9340
20	.9333	.9327	.9321	.9315	.9308	.9302	.9296	.9290	.9284	.9278
21	.9272	.9265	.9259	.9253	.9247	.9241	.9235	.9229	.9223	.9217
22	.9211	.9204	.9198	.9192	.9186	.9180	.9174	.9168	.9162	.9156
23	.9150	.9144	.9138	.9132	.9126	.9121	.9115	.9109	.9103	.9097
24	.9091	.9085	.9079	.9073	.9067	.9061	.9056	.9050	.9044	.9038
25	.9032	.9026	.9021	.9015	.9009	.9003	.8997	.8992	.8986	.8980
26	.8974	.8969	.8963	.8957	.8951	.8946	.8940	.8934	.8929	.8923
27	.8917	.8912	.8906	.8900	.8895	.8889	.8883	.8878	.8872	.8866
28	.8861	.8855	.8850	.8844	.8838	.8833	.8827	.8822	.8816	.8811
29	.8805	.8799	.8794	.8788	.8783	.8778	.8772	.8766	.8761	.8755
30	.8750	.8745	.8739	.8734	.8728	.8723	.8717	.8712	.8707	.8701
31	.8696	.8690	.8685	.8680	.8674	.8669	.8663	.8658	.8653	.8647
32	.8642	.8637	.8631	.8626	.8621	.8616	.8610	.8605	.8600	.8594
33	.8589	.8584	.8579	.8573	.8568	.8563	.8558	.8552	.8547	.8542
34	.8537	.8531	.8526	.8521	.8516	.8511	.8506	.8500	.8495	.8490
35	.8485	.8480	.8475	.8469	.8464	.8459	.8454	.8449	.8444	.8439
36	.8434	.8429	.8424	.8419	.8413	.8408	.8403	.8398	.8393	.8388
37	.8383	.8378	.8373	.8368	.8363	.8358	.8353	.8348	.8343	.8338
38	.8333	.8328	.8323	.8318	.8314	.8309	.8304	.8299	.8294	.8289
39	.8284	.8279	.8274	.8269	.8264	.8260	.8255	.8250	.8245	.8240
40	.8235	.8230	.8226	.8221	.8216	.8211	.8206	.8202	.8197	.8192
41	.8187	.8182	.8178	.8173	.8168	.8163	.8159	.8154	.8149	.8144
42	.8140	.8135	.8130	.8125	.8121	.8116	.8111	.8107	.8102	.8097
43	.8092	.8088	.8083	.8079	.8074	.8069	.8065	.8060	.8055	.8051
44	.8046	.8041	.8037	.8032	.8028	.8023	.8018	.8014	.8009	.8005
45	.8000	.7995	.7991	.7986	.7982	.7977	.7973	.7968	.7964	.7959
46	.7955	.7950	.7946	.7941	.7937	.7932	.7928	.7923	.7919	.7914
47	.7910	.7905	.7901	.7896	.7892	.7887	.7883	.7878	.7874	.7870
48	.7865	.7861	.7856	.7852	.7848	.7843	.7839	.7834	.7830	.7826
49	.7821	.7817	.7812	.7808	.7804	.7799	.7795	.7791	.7786	.7782
50	.7778	.7773	.7769	.7765	.7761	.7756	.7752	.7748	.7743	.7739
51	.7735	.7731	.7726	.7722	.7718	.7714	.7709	.7705	.7701	.7697
52	.7692	.7688	.7684	.7680	.7675	.7671	.7667	.7663	.7659	.7654
53	.7650	.7646	.7642	.7638	.7634	.7630	.7625	.7621	.7617	.7613
54	.7609	.7605	.7600	.7596	.7592	.7588	.7584	.7580	.7576	.7572
55	.7568	.7564	.7559	.7555	.7551	.7547	.7543	.7539	.7535	.7531

TABLE 19.—Specific Gravities at 60° F (15.556° C) Corresponding to Degrees Baumé for Liquids Lighter than Water—Continued

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
55	0.7568	0.7564	0.7559	0.7555	0.7551	0.7547	0.7543	0.7539	0.7535	0.7531
56	.7527	.7523	.7519	.7515	.7511	.7507	.7503	.7499	.7495	.7491
57	.7487	.7483	.7479	.7475	.7471	.7467	.7463	.7459	.7455	.7451
58	.7447	.7443	.7439	.7435	.7431	.7427	.7423	.7419	.7415	.7411
59	.7407	.7403	.7400	.7396	.7392	.7388	.7384	.7380	.7376	.7372
60	.7368	.7365	.7361	.7357	.7353	.7349	.7345	.7341	.7338	.7334
61	.7330	.7326	.7322	.7318	.7315	.7311	.7307	.7303	.7299	.7296
62	.7292	.7288	.7284	.7280	.7277	.7273	.7269	.7265	.7261	.7258
63	.7254	.7250	.7246	.7243	.7239	.7235	.7231	.7228	.7224	.7220
64	.7216	.7213	.7209	.7205	.7202	.7198	.7194	.7191	.7187	.7183
65	.7179	.7176	.7172	.7168	.7165	.7161	.7157	.7154	.7150	.7147
66	.7143	.7139	.7136	.7132	.7128	.7125	.7121	.7117	.7114	.7110
67	.7107	.7103	.7099	.7096	.7092	.7089	.7085	.7081	.7078	.7074
68	.7071	.7067	.7064	.7060	.7056	.7053	.7049	.7046	.7042	.7039
69	.7035	.7032	.7028	.7025	.7021	.7018	.7014	.7011	.7007	.7004
70	.7000	.6997	.6993	.6990	.6986	.6983	.6979	.6976	.6972	.6969
71	.6965	.6962	.6958	.6955	.6951	.6948	.6944	.6941	.6938	.6934
72	.6931	.6927	.6924	.6920	.6917	.6914	.6910	.6907	.6903	.6900
73	.6897	.6893	.6890	.6886	.6883	.6880	.6876	.6873	.6869	.6866
74	.6863	.6859	.6856	.6853	.6849	.6846	.6843	.6839	.6836	.6833
75	.6829	.6826	.6823	.6819	.6816	.6813	.6809	.6806	.6803	.6799
76	.6796	.6793	.6790	.6786	.6783	.6780	.6776	.6773	.6770	.6767
77	.6763	.6760	.6757	.6753	.6750	.6747	.6744	.6741	.6737	.6734
78	.6731	.6728	.6724	.6721	.6718	.6715	.6711	.6708	.6705	.6702
79	.6699	.6695	.6692	.6689	.6686	.6683	.6679	.6676	.6673	.6670
80	.6667	.6663	.6660	.6657	.6654	.6651	.6648	.6645	.6641	.6638
81	.6635	.6632	.6629	.6626	.6623	.6619	.6616	.6613	.6610	.6607
82	.6604	.6601	.6598	.6594	.6591	.6588	.6585	.6582	.6579	.6576
83	.6573	.6570	.6567	.6564	.6560	.6557	.6554	.6551	.6548	.6545
84	.6542	.6539	.6536	.6533	.6530	.6527	.6524	.6521	.6518	.6515
85	.6512	.6509	.6506	.6503	.6500	.6497	.6494	.6490	.6487	.6484
86	.6482	.6479	.6476	.6473	.6470	.6467	.6464	.6461	.6458	.6455
87	.6452	.6449	.6446	.6443	.6440	.6437	.6434	.6431	.6428	.6425
88	.6422	.6419	.6416	.6413	.6410	.6407	.6404	.6401	.6399	.6396
89	.6393	.6390	.6387	.6384	.6381	.6378	.6375	.6372	.6369	.6367
90	.6364	.6361	.6358	.6355	.6352	.6349	.6346	.6343	.6341	.6338
91	.6335	.6332	.6329	.6326	.6323	.6321	.6318	.6315	.6312	.6309
92	.6306	.6303	.6301	.6298	.6295	.6292	.6289	.6286	.6284	.6281
93	.6278	.6275	.6272	.6270	.6267	.6264	.6261	.6258	.6256	.6253
94	.6250	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225
95	.6222	.6219	.6217	.6214	.6211	.6208	.6206	.6203	.6200	.6197
96	.6195	.6192	.6189	.6186	.6184	.6181	.6178	.6176	.6173	.6170
97	.6167	.6165	.6162	.6159	.6157	.6154	.6151	.6148	.6146	.6143
98	.6140	.6138	.6135	.6132	.6130	.6127	.6124	.6122	.6119	.6116
99	.6114	.6111	.6108	.6106	.6103	.6100	.6098	.6095	.6092	.6090
100	.6087									

TABLE 20.—Conversion of Density Basis

Prepared for use in reducing readings of a hydrometer graduated to indicate density or specific gravity at a specified standard temperature, T , referred to water at a specified temperature, T' , as unity, to the basis of another standard temperature, t , and reference temperature, t' .

The factor Δ (given in units of the sixth decimal place), multiplied by the density or specific-gravity reading, gives the correction to be applied to the reading to reduce it to the required basis.

Suppose a hydrometer indicates specific gravity at $\frac{20^\circ}{4^\circ}\text{C}$, and it is required to know the correction in order that it shall indicate specific gravity at $\frac{15.56}{15.56}\text{C}$, then,

$$D_{\frac{15.56}{15.56}}^{\frac{20^\circ}{4^\circ}} = D_{\frac{20^\circ}{4^\circ}} + \Delta D_{\frac{20^\circ}{4^\circ}}$$

That is, if the hydrometer indicates correctly a specific gravity of 1.5760 at $\frac{20^\circ}{4^\circ}$, then at $\frac{15.56}{15.56}$ the reading of the instrument will be too low by $1.5760 \times 0.001062 = 0.0017$. A correction of 0.0017 must therefore be added to the indication of the hydrometer.

Or, if a maker using standards indicating $D_{\frac{15.56}{15.56}}$ wishes to graduate a hydrometer to indicate density at 20°C referred to water at 4°C ($D_{\frac{20}{4}}$), the readings of the standard must be corrected by use of the factor $+0.001062$.

Suppose the standard reads.....

The corresponding correction is $1.6 \times 0.001062 = \dots\dots\dots +0.0017$

Corrected reading..... 1.5777

The table is calculated for Jena 16^{III} glass.

Given Basis of Density	Required Basis of Density $\frac{t}{t'}$									
	$D_{\frac{25^\circ}{4^\circ}\text{C}}$	$D_{\frac{20}{4}}$	$D_{\frac{17.5}{4}}$	$D_{\frac{15.56}{4}}$	$D_{\frac{15}{4}}$	$D_{\frac{15}{15}}$	$D_{\frac{15.56}{15.56}}$	$D_{\frac{17.5}{17.5}}$	$D_{\frac{20}{20}}$	$D_{\frac{25}{25}}$
$\frac{T}{T'}$	Δ (In Units of the Sixth Decimal Place)									
$D_{\frac{25^\circ}{4^\circ}\text{C}}$	0	+ 115	+ 172	+ 217	+ 230	+1104	+1177	+1459	+1884	+2931
$D_{\frac{20}{4}}$	- 115	0	+ 58	+ 102	+ 115	+ 989	+1062	+1345	+1769	+2816
$D_{\frac{17.5}{4}}$	- 172	- 58	0	+ 45	+ 58	+ 932	+1005	+1287	+1711	+2758
$D_{\frac{15.56}{4}}$	- 217	- 102	- 45	0	+ 13	+ 887	+ 960	+1242	+1667	+2713
$D_{\frac{15}{4}}$	- 230	- 115	- 58	- 13	0	+ 874	+ 947	+1229	+1654	+2700
$D_{\frac{15}{15}}$	-1103	- 988	- 931	- 886	- 873	0	+ 73	+ 354	+ 779	+1826
$D_{\frac{15.56}{15.56}}$	-1176	-1061	-1004	- 960	- 947	- 73	0	+ 281	+ 706	+1752
$D_{\frac{17.5}{17.5}}$	-1457	-1343	-1285	-1240	-1227	- 354	- 281	0	+ 424	+1471
$D_{\frac{20}{20}}$	-1881	-1766	-1708	-1664	-1651	- 778	- 705	- 423	0	+1046
$D_{\frac{25}{25}}$	-2923	-2808	-2751	-2707	-2694	-1821	-1748	-1468	-1044	0

TABLE 21.—Weight (in grams), at Various Pressures and Temperatures, of 1 Liter of Dry Air Containing 0.04 Per Cent of CO₂

[Computed from the formula $C = \frac{1.293052}{1 + 0.00367t} \times \frac{h}{760}$, where h is pressure in mm of mercury at 0° C, and standard gravity, and t is temperature in degrees centigrade]

Temperature in Deg. C	Pressure in mm of Hg (0° C, Standard Gravity)											
	720	725	730	735	740	745	750	755	760	765	770	775
15	1.1611	1.1691	1.1772	1.1853	1.1933	1.2014	1.2095	1.2175	1.2256	1.2336	1.2417	1.2498
16	1.1571	1.1651	1.1731	1.1812	1.1892	1.1972	1.2053	1.2133	1.2213	1.2294	1.2374	1.2454
17	1.1531	1.1611	1.1691	1.1771	1.1851	1.1931	1.2011	1.2091	1.2171	1.2251	1.2331	1.2411
18	1.1491	1.1571	1.1650	1.1730	1.1810	1.1890	1.1970	1.2049	1.2129	1.2209	1.2289	1.2369
19	1.1451	1.1531	1.1611	1.1690	1.1770	1.1849	1.1929	1.2008	1.2088	1.2167	1.2247	1.2326
20	1.1412	1.1492	1.1571	1.1650	1.1729	1.1809	1.1888	1.1967	1.2046	1.2126	1.2205	1.2284
21	1.1373	1.1452	1.1531	1.1610	1.1689	1.1768	1.1847	1.1926	1.2005	1.2084	1.2163	1.2242
22	1.1335	1.1414	1.1492	1.1571	1.1650	1.1728	1.1807	1.1886	1.1965	1.2043	1.2122	1.2201
23	1.1296	1.1375	1.1453	1.1532	1.1610	1.1689	1.1767	1.1846	1.1924	1.2002	1.2081	1.2159
24	1.1258	1.1337	1.1415	1.1493	1.1571	1.1649	1.1727	1.1806	1.1884	1.1962	1.2040	1.2118
25	1.1220	1.1298	1.1376	1.1454	1.1532	1.1610	1.1688	1.1766	1.1844	1.1922	1.2000	1.2078
26	1.1183	1.1261	1.1338	1.1416	1.1494	1.1571	1.1649	1.1727	1.1804	1.1882	1.1959	1.2037
27	1.1146	1.1223	1.1300	1.1378	1.1455	1.1533	1.1610	1.1687	1.1765	1.1842	1.1920	1.1997
28	1.1108	1.1186	1.1263	1.1340	1.1417	1.1494	1.1571	1.1648	1.1726	1.1803	1.1880	1.1957
29	1.1072	1.1149	1.1225	1.1302	1.1379	1.1456	1.1533	1.1610	1.1687	1.1764	1.1840	1.1917
30	1.1035	1.1112	1.1188	1.1265	1.1342	1.1418	1.1495	1.1571	1.1648	1.1725	1.1801	1.1878
31	1.0999	1.1075	1.1151	1.1228	1.1304	1.1381	1.1457	1.1533	1.1610	1.1686	1.1762	1.1839

TABLE 22.—Buoyancy Constants (mg/cm³)

[Difference in milligrams between the mass and the apparent weight of 1 cubic centimeter of water weighed with brass weights ($d=8.4$) in air at various temperatures and barometer readings (unreduced). A humidity of 50 per cent saturation is assumed. To find the weight of 1 cubic centimeter of air under the conditions assumed in this table, multiply the buoyancy constant by 1.135 (42/37)]

Pressure		Temperature in Degrees Centigrade			
		15	20	25	30
Observed Pressure in Millimeters.	640	0.904	0.886	0.869	0.852
	650	0.918	0.900	0.883	0.866
	660	0.932	0.914	0.897	0.879
	670	0.946	0.928	0.911	0.893
	680	0.960	0.942	0.924	0.906
	690	0.975	0.956	0.938	0.920
	700	0.989	0.970	0.952	0.933
	705	0.996	0.977	0.958	0.940
	710	1.003	0.984	0.965	0.947
	715	1.010	0.991	0.972	0.953
	720	1.017	0.998	0.979	0.960
	725	1.024	1.004	0.985	0.967
	730	1.031	1.011	0.992	0.973
	735	1.038	1.018	0.999	0.980
	740	1.045	1.025	1.006	0.987
	745	1.052	1.032	1.013	0.994
	750	1.059	1.039	1.020	1.000
	755	1.067	1.046	1.027	1.007
	760	1.074	1.053	1.034	1.014
	765	1.081	1.060	1.040	1.020
	770	1.088	1.067	1.047	1.027
	775	1.095	1.074	1.054	1.034
	780	1.102	1.081	1.061	1.041

TABLE 23.—Apparent Weight (in grams) of Water in Air

[This table gives the apparent weight, for temperatures between 15° and 30° C, humidity 50 per cent, uncorrected barometer reading 76 cm of certain volumes of water weighed with brass weights. This table is based on the data given in Tables 1 and 22, and may be conveniently employed to determine definite volumes of water for calibrating instruments. The table assumes the air to be at the same temperature as the water]

Temp. in Degrees C	2000 cc	1000 cc	500 cc	400 cc	300 cc	250 cc	150 cc
15	1996.11	998.05	499.03	399.22	299.42	249.51	149.71
16	1995.80	997.90	498.95	399.16	299.37	249.48	149.68
17	1995.48	997.74	498.87	399.10	299.32	249.43	149.66
18	1995.13	997.56	498.78	399.03	299.27	249.39	149.63
19	1994.76	997.38	498.69	398.95	299.21	249.34	149.61
20	1994.36	997.18	498.59	398.87	299.15	249.30	149.58
21	1993.95	996.97	498.49	398.79	299.09	249.24	149.55
22	1993.51	996.76	498.38	398.70	299.03	249.19	149.51
23	1993.06	996.53	498.26	398.61	298.96	249.13	149.48
24	1992.58	996.29	498.15	398.52	298.89	249.07	149.44
25	1992.09	996.04	498.02	398.42	298.81	249.01	149.41
26	1991.57	995.79	497.89	398.31	298.74	248.95	149.37
27	1991.04	995.52	497.76	398.21	298.66	248.88	149.33
28	1990.49	995.24	497.62	398.10	298.57	248.81	149.29
29	1989.92	994.96	497.48	397.98	298.49	248.74	149.24
30	1989.33	994.66	497.33	397.87	298.40	248.67	149.20

TABLE 24.—Temperature Correction for Glass Volumetric Apparatus

[This table gives the correction to be added to actual capacity (determined at certain temperatures) to give the capacity at the standard temperature, 20° C. Conversely, by subtracting the corrections from the indicated capacity of an instrument standard at 20° C the corresponding capacity at other temperatures is obtained. The table assumes for the cubical coefficient of expansion of glass 0.000025 per degree centigrade. The coefficients of expansion of glasses used for volumetric instruments vary from 0.000023 to 0.000028]

Temp. in Degrees C	2000 cc	1000 cc	500 cc	400 cc	300 cc	250 cc
15	+0.25	+0.12	+0.06	+0.05	+0.04	+0.031
16	+ .20	+ .10	+ .05	+ .04	+ .03	+ .025
17	+ .15	+ .08	+ .04	+ .03	+ .02	+ .019
18	+ .10	+ .05	+ .02	+ .02	+ .02	+ .012
19	+ .05	+ .02	+ .01	+ .01	+ .01	+ .006
21	−0.05	−0.02	−0.01	−0.01	−0.01	−0.006
22	− .10	− .05	− .02	− .02	− .02	− .012
23	− .15	− .08	− .04	− .03	− .02	− .019
24	− .20	− .10	− .05	− .04	− .03	− .025
25	− .25	− .12	− .06	− .05	− .04	− .031
26	−0.30	−0.15	−0.08	−0.06	−0.04	−0.038
27	− .35	− .18	− .09	− .07	− .05	− .044
28	− .40	− .20	− .10	− .08	− .06	− .050
29	− .45	− .22	− .11	− .09	− .07	− .056
30	− .50	− .25	− .12	− .10	− .08	− .062

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR

Tables 25 to 37 are intended for the calculation of capacities of glass vessels of common sizes from the weight (in air) of the water contained or delivered. They give for each nominal capacity and observed temperature the amounts to be added to the apparent weight (in air against brass weights) of the water contained in or delivered by a glass vessel to give the capacity in cubic centimeters at 20° C. They are calculated on the following data assumed as approximating ordinary conditions:

Observed barometric pressure..... 76 cm
 Relative humidity..... 50 per cent
 Coefficient of expansion of glass..... 0.000025 per deg. C

EXAMPLE OF USE OF TABLE

Determination of capacity of glass measuring flask marked "To contain 250 cc at 20° C."

Apparent weight of water at the observed temperature 22°₃ C..... 249.198g
 From Table 25, correction..... 0.813

Actual capacity at 20°..... 250.011 cc

TABLE 25.—Indicated Capacity 250 cc

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in cubic centimeters at 20° C]

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.518	0.521	0.524	0.528	0.530	0.534	0.537	0.540	0.543	0.546
16	.550	.554	.556	.560	.563	.567	.570	.574	.578	.581
17	.584	.588	.592	.596	.599	.603	.606	.610	.614	.618
18	.622	.626	.630	.633	.638	.642	.646	.649	.654	.658
19	.662	.666	.670	.674	.679	.683	.687	.692	.696	.700
20	.705	.709	.714	.718	.722	.727	.732	.736	.741	.746
21	.750	.754	.760	.764	.769	.774	.778	.784	.788	.793
22	.798	.804	.808	.813	.818	.824	.828	.834	.839	.844
23	.849	.854	.860	.865	.870	.875	.881	.886	.892	.897
24	.902	.908	.913	.919	.924	.930	.936	.941	.947	.952
25	.958	.964	.969	.975	.981	.986	.993	.998	1.004	1.010
26	1.016	1.022	1.028	1.034	1.040	1.046	1.052	1.058	1.064	1.070
27	1.076	1.082	1.089	1.095	1.101	1.108	1.114	1.120	1.126	1.132
28	1.139	1.146	1.152	1.158	1.165	1.172	1.178	1.184	1.191	1.198
29	1.204	1.211	1.218							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in cubic centimeters at 20° C]

TABLE 26.—Indicated Capacity 200 cc

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.414	0.417	0.419	0.422	0.424	0.427	0.430	0.432	0.435	0.437
16	.440	.443	.445	.448	.451	.454	.456	.459	.462	.465
17	.468	.470	.473	.477	.479	.482	.485	.488	.491	.494
18	.497	.501	.504	.507	.510	.513	.516	.519	.523	.526
19	.529	.533	.536	.540	.543	.546	.550	.553	.557	.560
20	.564	.567	.571	.574	.578	.582	.585	.589	.593	.596
21	.600	.604	.608	.612	.615	.619	.623	.627	.631	.635
22	.639	.643	.647	.650	.655	.659	.663	.667	.671	.675
23	.679	.683	.688	.692	.696	.700	.705	.709	.713	.717
24	.722	.726	.731	.735	.739	.744	.748	.753	.757	.762
25	.766	.771	.775	.780	.785	.789	.794	.799	.803	.808
26	.813	.818	.822	.827	.832	.837	.842	.846	.851	.856
27	.861	.866	.871	.876	.881	.886	.891	.896	.901	.906
28	.911	.917	.922	.927	.932	.937	.942	.947	.953	.958
29	.963	.969	.974							

TABLE 27.—Indicated Capacity 150 cc

15	0.311	0.313	0.314	0.316	0.318	0.320	0.322	0.324	0.326	0.328
16	.330	.332	.334	.336	.338	.340	.342	.344	.346	.349
17	.351	.353	.355	.357	.359	.362	.364	.366	.368	.371
18	.373	.375	.378	.380	.383	.385	.387	.390	.392	.395
19	.397	.400	.402	.405	.408	.410	.412	.415	.418	.420
20	.423	.425	.428	.431	.433	.436	.439	.442	.445	.448
21	.450	.453	.456	.459	.461	.464	.467	.470	.473	.476
22	.479	.483	.485	.488	.491	.494	.497	.500	.503	.506
23	.509	.512	.516	.519	.522	.525	.529	.532	.535	.538
24	.541	.545	.548	.551	.554	.558	.562	.565	.568	.571
25	.575	.578	.581	.585	.588	.592	.596	.599	.602	.606
26	.610	.613	.617	.620	.624	.628	.631	.635	.638	.642
27	.645	.649	.653	.657	.661	.664	.668	.672	.676	.680
28	.684	.688	.691	.695	.699	.703	.707	.711	.715	.719
29	.722	.726	.730							

TABLE 28.—Indicated Capacity 100 cc

15	0.207	0.208	0.210	0.211	0.212	0.213	0.215	0.216	0.217	0.219
16	.220	.221	.223	.224	.225	.227	.228	.230	.231	.232
17	.234	.235	.237	.238	.240	.241	.243	.244	.246	.247
18	.249	.250	.252	.253	.255	.257	.258	.260	.261	.263
19	.265	.266	.268	.270	.272	.273	.275	.277	.278	.280
20	.282	.284	.285	.287	.289	.291	.293	.294	.296	.298
21	.300	.302	.304	.306	.308	.310	.311	.314	.315	.317
22	.319	.321	.323	.325	.327	.329	.331	.333	.336	.338
23	.340	.342	.344	.346	.348	.350	.352	.354	.357	.359
24	.361	.363	.365	.368	.370	.372	.374	.376	.379	.381
25	.383	.386	.388	.390	.392	.395	.397	.399	.402	.404
26	.406	.409	.411	.414	.416	.418	.421	.423	.426	.428
27	.431	.433	.436	.438	.440	.443	.446	.448	.451	.453
28	.456	.458	.461	.463	.466	.469	.471	.474	.476	.479
29	.482	.484	.487							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in cubic centimeters at 20° C]

TABLE 29.—Indicated Capacity 90 cc

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.186	0.188	0.189	0.190	0.191	0.192	0.193	0.194	0.196	0.197
16	.198	.199	.200	.202	.203	.204	.205	.207	.208	.209
17	.210	.212	.213	.214	.216	.217	.218	.220	.221	.222
18	.224	.225	.227	.228	.230	.231	.232	.234	.235	.237
19	.238	.240	.241	.243	.244	.246	.247	.249	.251	.252
20	.254	.255	.257	.258	.260	.262	.263	.265	.267	.268
21	.270	.272	.273	.275	.277	.278	.280	.282	.284	.286
22	.287	.289	.291	.293	.295	.296	.298	.300	.302	.304
23	.306	.308	.309	.311	.313	.315	.317	.319	.321	.323
24	.325	.327	.329	.331	.333	.335	.337	.339	.341	.343
25	.345	.347	.349	.351	.353	.355	.357	.359	.362	.364
26	.366	.368	.370	.372	.374	.377	.379	.381	.383	.385
27	.388	.390	.392	.394	.396	.399	.401	.403	.406	.408
28	.410	.412	.415	.417	.419	.422	.424	.426	.429	.431
29	.434	.436	.438							

TABLE 30.—Indicated Capacity 80 cc

15	0.166	0.167	0.168	0.169	0.170	0.171	0.172	0.173	0.174	0.175
16	.176	.177	.178	.179	.180	.181	.183	.184	.185	.186
17	.187	.188	.189	.191	.192	.193	.194	.195	.196	.198
18	.199	.200	.201	.203	.204	.205	.206	.208	.209	.210
19	.212	.213	.214	.216	.217	.218	.220	.221	.223	.224
20	.226	.227	.228	.230	.231	.233	.234	.236	.237	.239
21	.240	.241	.243	.245	.246	.248	.249	.251	.252	.254
22	.255	.257	.259	.260	.262	.264	.265	.267	.268	.270
23	.272	.273	.275	.277	.278	.280	.282	.284	.285	.287
24	.289	.290	.292	.294	.296	.298	.299	.301	.303	.305
25	.306	.308	.310	.312	.314	.316	.318	.320	.321	.323
26	.325	.327	.329	.331	.333	.335	.337	.339	.341	.342
27	.344	.346	.348	.350	.352	.354	.356	.358	.360	.362
28	.365	.367	.369	.371	.373	.375	.377	.379	.381	.383
29	.385	.387	.390							

TABLE 31.—Indicated Capacity 70 cc

15	0.145	0.146	0.147	0.148	0.148	0.149	0.150	0.151	0.152	0.153
16	.154	.155	.156	.157	.158	.159	.160	.161	.162	.163
17	.164	.165	.166	.167	.168	.169	.170	.171	.172	.173
18	.174	.175	.176	.177	.178	.180	.181	.182	.183	.184
19	.185	.186	.188	.189	.190	.191	.192	.194	.195	.196
20	.197	.199	.200	.201	.202	.204	.205	.206	.207	.209
21	.210	.211	.213	.214	.216	.217	.218	.220	.221	.222
22	.224	.225	.226	.228	.229	.230	.232	.233	.235	.236
23	.238	.239	.241	.242	.244	.245	.247	.248	.250	.251
24	.253	.254	.256	.257	.259	.260	.262	.263	.265	.267
25	.268	.270	.271	.273	.274	.276	.278	.280	.281	.283
26	.284	.286	.288	.289	.291	.293	.294	.296	.298	.299
27	.301	.303	.305	.307	.308	.310	.312	.314	.315	.317
28	.319	.321	.323	.324	.326	.328	.330	.332	.333	.335
29	.337	.339	.341							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in cubic centimeters at 20° C]

TABLE 32.—Indicated Capacity 60 cc

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.124	0.125	0.126	0.127	0.127	0.128	0.129	0.130	0.130	0.131
16	.132	.133	.134	.134	.135	.136	.137	.138	.139	.140
17	.140	.141	.142	.143	.144	.145	.145	.147	.147	.148
18	.150	.150	.151	.152	.153	.154	.155	.156	.157	.158
19	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
20	.169	.170	.171	.172	.173	.175	.176	.177	.178	.179
21	.180	.181	.182	.183	.185	.186	.187	.188	.189	.190
22	.192	.193	.194	.195	.196	.198	.199	.200	.201	.202
23	.204	.205	.206	.208	.209	.210	.211	.213	.214	.215
24	.216	.218	.219	.220	.222	.223	.225	.226	.227	.228
25	.230	.231	.232	.234	.235	.237	.238	.240	.241	.242
26	.244	.245	.247	.248	.250	.251	.253	.254	.255	.257
27	.258	.260	.261	.263	.264	.266	.267	.269	.270	.272
28	.273	.275	.276	.278	.280	.281	.283	.284	.286	.288
29	.289	.291	.292							

TABLE 33.—Indicated Capacity 50 cc

15	0.104	0.104	0.105	0.106	0.106	0.107	0.107	0.108	0.109	0.109
16	.110	.111	.111	.112	.113	.113	.114	.115	.116	.116
17	.117	.118	.118	.119	.120	.121	.121	.122	.123	.124
18	.124	.125	.126	.127	.128	.128	.129	.130	.131	.132
19	.132	.133	.134	.135	.136	.137	.137	.138	.139	.140
20	.141	.142	.143	.144	.144	.145	.146	.147	.148	.149
21	.150	.151	.152	.153	.154	.155	.156	.157	.158	.159
22	.160	.161	.162	.163	.164	.165	.166	.167	.168	.169
23	.170	.171	.172	.173	.174	.175	.176	.177	.178	.179
24	.180	.182	.183	.184	.185	.186	.187	.188	.189	.190
25	.192	.193	.194	.195	.196	.197	.199	.200	.201	.202
26	.203	.204	.206	.207	.208	.209	.210	.212	.213	.214
27	.215	.216	.218	.219	.220	.222	.223	.224	.225	.226
28	.228	.229	.230	.232	.233	.234	.236	.237	.238	.240
29	.241	.242	.244							

TABLE 34.—Indicated Capacity 45 cc

15	0.093	0.094	0.094	0.095	0.095	0.096	0.097	0.097	0.098	0.098
16	.099	.100	.100	.101	.101	.102	.103	.103	.104	.105
17	.105	.106	.107	.107	.108	.108	.109	.110	.111	.111
18	.112	.113	.113	.114	.115	.115	.116	.117	.118	.118
19	.119	.120	.121	.121	.122	.123	.124	.124	.125	.126
20	.127	.128	.128	.129	.130	.131	.132	.132	.133	.134
21	.135	.136	.137	.138	.138	.139	.140	.141	.142	.143
22	.144	.145	.145	.146	.147	.148	.149	.150	.151	.152
23	.153	.154	.155	.156	.157	.158	.159	.160	.160	.161
24	.162	.163	.164	.165	.166	.167	.168	.169	.170	.171
25	.172	.173	.174	.176	.177	.178	.179	.180	.181	.182
26	.183	.184	.185	.186	.187	.188	.189	.190	.192	.193
27	.194	.195	.196	.197	.198	.199	.201	.202	.203	.204
28	.205	.206	.207	.209	.210	.211	.212	.213	.214	.216
29	.217	.218	.219							

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF
GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued**

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in cubic centimeters at 20° C]

TABLE 35.—Indicated Capacity 40 cc

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.083	0.083	0.084	0.084	0.085	0.085	0.086	0.086	0.087	0.087
16	.088	.089	.089	.090	.090	.091	.091	.092	.092	.093
17	.094	.094	.095	.095	.096	.096	.097	.098	.098	.099
18	.099	.100	.101	.101	.102	.102	.103	.104	.105	.105
19	.106	.107	.107	.108	.109	.109	.110	.111	.111	.112
20	.113	.113	.114	.115	.116	.116	.117	.118	.119	.119
21	.120	.121	.122	.122	.123	.124	.125	.125	.126	.127
22	.128	.129	.129	.130	.131	.132	.133	.133	.134	.135
23	.136	.137	.138	.138	.139	.140	.141	.142	.143	.143
24	.144	.145	.146	.147	.148	.149	.150	.151	.151	.152
25	.153	.154	.155	.156	.157	.158	.159	.160	.161	.162
26	.163	.164	.164	.165	.166	.167	.168	.169	.170	.171
27	.172	.173	.174	.175	.176	.177	.178	.179	.180	.181
28	.182	.183	.184	.185	.186	.187	.188	.189	.191	.192
29	.193	.194	.195							

TABLE 36.—Indicated Capacity 35 cc

15	0.073	0.073	0.073	0.074	0.074	0.075	0.075	0.076	0.076	0.076
16	.077	.078	.078	.078	.079	.079	.080	.080	.081	.081
17	.082	.082	.083	.083	.084	.084	.085	.085	.086	.086
18	.087	.088	.088	.089	.089	.090	.090	.091	.091	.092
19	.092	.093	.094	.094	.095	.096	.096	.097	.097	.098
20	.099	.099	.100	.100	.101	.102	.102	.103	.104	.104
21	.105	.106	.106	.107	.108	.108	.109	.110	.110	.111
22	.112	.113	.113	.114	.115	.115	.116	.117	.117	.118
23	.119	.120	.120	.121	.122	.122	.123	.124	.125	.126
24	.126	.127	.128	.129	.129	.130	.131	.132	.133	.133
25	.134	.135	.136	.137	.137	.138	.139	.140	.141	.141
26	.142	.143	.144	.145	.146	.146	.147	.148	.149	.150
27	.151	.152	.152	.153	.154	.155	.156	.157	.158	.159
28	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
29	.169	.170	.170							

TABLE 37.—Indicated Capacity 30 cc

15	0.062	0.063	0.063	0.063	0.064	0.064	0.064	0.065	0.065	0.066
16	.066	.066	.067	.067	.068	.068	.068	.069	.069	.070
17	.070	.071	.071	.071	.072	.072	.073	.073	.074	.074
18	.075	.075	.076	.076	.077	.077	.077	.078	.078	.079
19	.079	.080	.080	.081	.081	.082	.082	.083	.084	.084
20	.085	.085	.086	.086	.087	.087	.088	.088	.089	.089
21	.090	.091	.091	.092	.092	.093	.093	.094	.094	.095
22	.096	.096	.097	.098	.098	.099	.099	.100	.101	.101
23	.102	.103	.103	.104	.104	.105	.106	.106	.107	.108
24	.108	.109	.110	.110	.111	.112	.112	.113	.114	.114
25	.115	.116	.116	.117	.118	.118	.119	.120	.121	.121
26	.122	.123	.123	.124	.125	.126	.126	.127	.128	.128
27	.129	.130	.131	.131	.132	.133	.134	.134	.135	.136
28	.137	.137	.138	.139	.140	.141	.141	.142	.143	.144
29	.145	.145	.146							

TABLE 38.—Density (in grams per milliliter) of Water at Temperatures from 0° to 102° C¹

Temp., Deg. C	Density	Temp., Deg. C	Density	Temp., Deg. C	Density
0	0.99987	35	0.99406	70	0.97781
1	.99993	36	.99371	71	.97723
2	.99997	37	.99336	72	.97666
3	.99999	38	.99299	73	.97607
4	1.00000	39	.99262	74	.97548
5	.99999	40	.99224	75	.97489
6	.99997	41	.99186	76	.97428
7	.99993	42	.99147	77	.97368
8	.99988	43	.99107	78	.97307
9	.99981	44	.99066	79	.97245
10	.99973	45	.99024	80	.97183
11	.99963	46	.98982	81	.97120
12	.99952	47	.98940	82	.97057
13	.99940	48	.98896	83	.96994
14	.99927	49	.98852	84	.96930
15	.99913	50	.98807	85	.96865
16	.99897	51	.98762	86	.96800
17	.99880	52	.98715	87	.96734
18	.99862	53	.98669	88	.96668
19	.99843	54	.98621	89	.96601
20	.99823	55	.98573	90	.96534
21	.99802	56	.98524	91	.96467
22	.99780	57	.98478	92	.96399
23	.99756	58	.98425	93	.96330
24	.99732	59	.98375	94	.96261
25	.99707	60	.98324	95	.96192
26	.99681	61	.98272	96	.96122
27	.99654	62	.98220	97	.96051
28	.99626	63	.98167	98	.95981
29	.99597	64	.98113	99	.95909
30	.99567	65	.98059	100	.95838
31	.99537	66	.98005	101	.95765
32	.99505	67	.97950	102	.95693
33	.99473	68	.97894		
34	.99440	69	.97838		
35	.99406	70	.97781		

¹ According to M. Thiesen, Wiss. Abh. der Physikalisch-Technischen Reichsanstalt, 4, No. 2: 1904.

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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS

SUPPLEMENT TO CIRCULAR 19

MASTER SCALES FOR THE GRADUATION OF HYDROMETERS

The accompanying tables were prepared for the use of hydrometer makers in the graduation of hydrometer scales to indicate percentages of ethyl alcohol by weight at 20° C or by volume at 60° F, and they give the proportional length of any part of the hydrometer scale, assuming that the entire scale has a length of 1000 mm¹ and that the hydrometer stem is of uniform cross section. For example, if it is required to construct a hydrometer scale having a certain range the spacing of the graduations of the scale should be made proportional to the differences of the lengths shown in the table for that range.

These tables were prepared from the alcoholometric tables published in Circular No. 19, 3d edition. The original work on which the tables are based is described in detail in the Bulletin of the Bureau of Standards, Vol. 9, p. 328 (Reprint No. 197). The indications of hydrometers graduated in accordance with these master scales will be on the basis officially adopted by the Bureau of Standards. Hydrometers may also be graduated to indicate percentages of "proof spirit," according to the official tables of the United States Bureau of Internal Revenue (adopted 1913), by the use of the accompanying master scale intended for the graduation of hydrometers to indicate percentages of alcohol by volume at 60° F. The percentage of proof spirit is in every case twice the percentage of alcohol by volume. For example, 25 per cent alcohol by volume is equivalent to 50 per cent proof spirit; 50 per cent alcohol by volume is equivalent to 100 per cent proof spirit. The spacing of the graduations for proof spirit hydrometers can therefore be taken directly from Table 2, the per cent alcohol by volume being multiplied by 2 in each case to give the equivalent per cent proof spirit.

¹ Any other convenient unit may be employed; the tabulated lengths will then be in that unit.

TABLE 1.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C

[Total length of scale 1000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
0.0	0.00	5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45
.1	0.71	.1	34.40	.1	63.51	.1	90.00	.1	115.99
.2	1.42	.2	35.02	.2	64.06	.2	90.50	.2	116.53
.3	2.13	.3	35.64	.3	64.61	.3	91.00	.3	117.07
.4	2.84	.4	36.26	.4	65.16	.4	91.50	.4	117.61
.5	3.55	.5	36.87	.5	65.71	.5	91.99	.5	118.15
.6	4.26	.6	37.48	.6	66.26	.6	92.48	.6	118.69
.7	4.97	.7	38.08	.7	66.81	.7	92.98	.7	119.23
.8	5.68	.8	38.68	.8	67.36	.8	93.48	.8	119.78
.9	6.38	.9	39.28	.9	67.91	.9	93.98	.9	120.33
1.0	7.08	6.0	39.88	11.0	68.45	16.0	94.49	21.0	120.88
.1	7.78	.1	40.48	.1	68.99	.1	95.00	.1	121.43
.2	8.48	.2	41.08	.2	69.53	.2	95.51	.2	121.98
.3	9.18	.3	41.68	.3	70.07	.3	96.02	.3	122.53
.4	9.88	.4	42.28	.4	70.61	.4	96.53	.4	123.08
.5	10.58	.5	42.88	.5	71.15	.5	97.04	.5	123.63
.6	11.28	.6	43.47	.6	71.69	.6	97.55	.6	124.18
.7	11.97	.7	44.06	.7	72.23	.7	98.06	.7	124.73
.8	12.66	.8	44.65	.8	72.77	.8	98.57	.8	125.28
.9	13.35	.9	45.24	.9	73.31	.9	99.08	.9	125.83
2.0	14.04	7.0	45.82	12.0	73.84	17.0	99.60	22.0	126.38
.1	14.73	.1	46.40	.1	74.37	.1	100.12	.1	126.94
.2	15.42	.2	46.98	.2	74.90	.2	100.64	.2	127.50
.3	16.11	.3	47.56	.3	75.43	.3	101.16	.3	128.06
.4	16.80	.4	48.14	.4	75.96	.4	101.68	.4	128.62
.5	17.49	.5	48.72	.5	76.49	.5	102.20	.5	129.19
.6	18.18	.6	49.30	.6	77.02	.6	102.72	.6	129.76
.7	18.87	.7	49.88	.7	77.55	.7	103.24	.7	130.33
.8	19.55	.8	50.46	.8	78.08	.8	103.76	.8	130.90
.9	20.22	.9	51.04	.9	78.61	.9	104.28	.9	131.47
3.0	20.89	8.0	51.62	13.0	79.13	18.0	104.80	23.0	132.04
.1	21.56	.1	52.19	.1	79.65	.1	105.32	.1	132.61
.2	22.22	.2	52.76	.2	80.17	.2	105.85	.2	133.18
.3	22.88	.3	53.33	.3	80.69	.3	106.38	.3	133.75
.4	23.54	.4	53.90	.4	81.21	.4	106.91	.4	134.32
.5	24.20	.5	54.47	.5	81.73	.5	107.44	.5	134.89
.6	24.85	.6	55.04	.6	82.25	.6	107.97	.6	135.46
.7	25.50	.7	55.61	.7	82.77	.7	108.50	.7	136.03
.8	26.15	.8	56.18	.8	83.29	.8	109.03	.8	136.60
.9	26.80	.9	56.75	.9	83.81	.9	109.56	.9	137.18
4.0	27.45	9.0	57.32	14.0	84.33	19.0	110.09	24.0	137.76
.1	28.09	.1	57.89	.1	84.85	.1	110.62	.1	138.34
.2	28.73	.2	58.46	.2	85.37	.2	111.15	.2	138.92
.3	29.37	.3	59.03	.3	85.89	.3	111.68	.3	139.50
.4	30.01	.4	59.60	.4	86.41	.4	112.21	.4	140.09
.5	30.64	.5	60.17	.5	86.93	.5	112.75	.5	140.68
.6	31.27	.6	60.73	.6	87.45	.6	113.29	.6	141.27
.7	31.90	.7	61.29	.7	87.97	.7	113.83	.7	141.86
.8	32.53	.8	61.85	.8	88.49	.8	114.37	.8	142.45
.9	33.16	.9	62.41	.9	89.00	.9	114.91	.9	143.04
5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45	25.0	143.63

TABLE 1.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	143.63	30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41
.1	144.22	.1	176.63	.1	213.88	.1	255.62	.1	301.85
.2	144.82	.2	177.33	.2	214.67	.2	256.50	.2	302.29
.3	145.42	.3	178.03	.3	215.46	.3	257.38	.3	303.23
.4	146.02	.4	178.73	.4	216.26	.4	258.26	.4	304.17
.5	146.62	.5	179.43	.5	217.06	.5	259.14	.5	305.12
.6	147.23	.6	180.13	.6	217.86	.6	260.02	.6	306.07
.7	147.84	.7	180.84	.7	218.66	.7	260.90	.7	307.02
.8	148.45	.8	181.55	.8	219.46	.8	261.79	.8	307.97
.9	149.06	.9	182.26	.9	220.26	.9	262.68	.9	308.92
26.0	149.67	31.0	182.97	36.0	221.06	41.0	263.57	46.0	309.88
.1	150.28	.1	183.68	.1	221.86	.1	264.46	.1	310.84
.2	150.90	.2	184.40	.2	222.67	.2	265.35	.2	311.80
.3	151.52	.3	185.12	.3	223.48	.3	266.24	.3	312.76
.4	152.14	.4	185.85	.4	224.29	.4	267.14	.4	313.72
.5	152.77	.5	186.58	.5	225.10	.5	268.04	.5	314.68
.6	153.40	.6	187.31	.6	225.91	.6	268.94	.6	315.64
.7	154.03	.7	188.04	.7	226.73	.7	269.84	.7	316.60
.8	154.66	.8	188.77	.8	227.55	.8	270.74	.8	317.56
.9	155.29	.9	189.51	.9	228.37	.9	271.64	.9	318.52
27.0	155.93	32.0	190.25	37.0	229.19	42.0	272.55	47.0	319.49
.1	156.57	.1	190.99	.1	230.01	.1	273.46	.1	320.46
.2	157.21	.2	191.73	.2	230.84	.2	274.37	.2	321.43
.3	157.85	.3	192.47	.3	231.67	.3	275.28	.3	322.40
.4	158.49	.4	193.21	.4	232.50	.4	276.19	.4	323.37
.5	159.14	.5	193.95	.5	233.34	.5	277.11	.5	324.34
.6	159.79	.6	194.69	.6	234.18	.6	278.03	.6	325.31
.7	160.44	.7	195.44	.7	235.02	.7	278.95	.7	326.28
.8	161.09	.8	196.19	.8	235.86	.8	279.87	.8	327.25
.9	161.74	.9	196.94	.9	236.70	.9	280.79	.9	328.22
28.0	162.40	33.0	197.69	38.0	237.54	43.0	281.71	48.0	329.19
.1	163.06	.1	198.45	.1	238.38	.1	282.63	.1	330.16
.2	163.72	.2	199.21	.2	239.23	.2	283.55	.2	331.14
.3	164.38	.3	199.97	.3	240.08	.3	284.48	.3	332.12
.4	165.04	.4	200.73	.4	240.93	.4	285.41	.4	333.10
.5	165.70	.5	201.49	.5	241.78	.5	286.34	.5	334.09
.6	166.37	.6	202.25	.6	242.63	.6	287.27	.6	335.08
.7	167.04	.7	203.01	.7	243.49	.7	288.20	.7	336.07
.8	167.71	.8	203.77	.8	244.35	.8	289.13	.8	337.06
.9	168.38	.9	204.53	.9	245.21	.9	290.07	.9	338.05
29.0	169.06	34.0	205.30	39.0	246.07	44.0	291.01	49.0	339.04
.1	169.74	.1	206.07	.1	246.93	.1	291.95	.1	340.03
.2	170.42	.2	206.84	.2	247.79	.2	292.89	.2	341.02
.3	171.10	.3	207.61	.3	248.65	.3	293.83	.3	342.01
.4	171.78	.4	208.38	.4	249.51	.4	294.77	.4	343.00
.5	172.47	.5	209.16	.5	250.38	.5	295.71	.5	343.99
.6	173.16	.6	209.94	.6	251.25	.6	296.65	.6	344.98
.7	173.85	.7	210.72	.7	252.12	.7	297.59	.7	345.97
.8	174.54	.8	211.51	.8	252.99	.8	298.53	.8	346.96
.9	175.23	.9	212.30	.9	253.86	.9	299.47	.9	347.96
30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41	50.0	348.96

TABLE 1.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
50.0	348.96	55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65
.1	349.96	.1	401.46	.1	455.21	.1	511.34	.1	569.85
.2	350.96	.2	402.52	.2	456.31	.2	512.49	.2	571.05
.3	351.96	.3	403.58	.3	457.41	.3	513.64	.3	572.25
.4	352.96	.4	404.64	.4	458.51	.4	514.79	.4	573.45
.5	353.97	.5	405.70	.5	459.61	.5	515.94	.5	574.65
.6	354.98	.6	406.76	.6	460.71	.6	517.09	.6	575.85
.7	355.99	.7	407.82	.7	461.82	.7	518.24	.7	577.05
.8	357.01	.8	408.88	.8	462.93	.8	519.39	.8	578.25
.9	358.03	.9	409.94	.9	464.04	.9	520.54	.9	579.46
51.0	359.05	56.0	411.00	61.0	465.15	66.0	521.70	71.0	580.67
.1	360.07	.1	412.06	.1	466.26	.1	522.86	.1	581.88
.2	361.09	.2	413.12	.2	467.37	.2	524.02	.2	583.09
.3	362.11	.3	414.18	.3	468.48	.3	525.18	.3	584.30
.4	363.13	.4	415.24	.4	469.59	.4	526.34	.4	585.51
.5	364.15	.5	416.31	.5	470.70	.5	527.50	.5	586.72
.6	365.17	.6	417.38	.6	471.81	.6	528.66	.6	587.93
.7	366.19	.7	418.45	.7	472.92	.7	529.82	.7	589.14
.8	367.22	.8	419.52	.8	474.03	.8	530.98	.8	590.35
.9	368.25	.9	420.59	.8	475.14	.9	532.14	.9	591.56
52.0	369.28	57.0	421.66	62.0	476.25	67.0	533.30	72.0	592.77
.1	370.31	.1	422.73	.1	477.37	.1	534.46	.1	593.99
.2	371.34	.2	423.80	.2	478.49	.2	535.62	.2	595.21
.3	372.37	.3	424.87	.3	479.61	.3	536.79	.3	596.43
.4	373.40	.4	425.94	.4	480.73	.4	537.96	.4	597.65
.5	374.43	.5	427.01	.5	481.85	.5	539.13	.5	598.87
.6	375.46	.6	428.08	.6	482.97	.6	540.30	.6	600.09
.7	376.49	.7	429.15	.7	484.09	.7	541.47	.7	601.31
.8	377.52	.8	430.22	.8	485.21	.8	542.64	.8	602.53
.9	378.55	.9	431.29	.9	486.33	.9	543.81	.9	603.75
53.0	379.58	58.0	432.37	63.0	487.46	68.0	544.98	73.0	604.98
.1	380.61	.1	433.45	.1	488.59	.1	546.15	.1	606.21
.2	381.64	.2	434.53	.2	489.72	.2	547.32	.2	607.44
.3	382.67	.3	435.61	.3	490.85	.3	548.49	.3	608.67
.4	383.70	.4	436.69	.4	491.98	.4	549.66	.4	609.90
.5	384.73	.5	437.77	.5	493.11	.5	550.84	.5	611.13
.6	385.76	.6	438.85	.6	494.24	.6	552.02	.6	612.36
.7	386.80	.7	439.93	.7	495.37	.7	553.20	.7	613.59
.8	387.84	.8	441.02	.8	496.50	.8	554.38	.8	614.82
.9	388.88	.9	442.11	.9	497.64	.9	555.56	.9	616.05
54.0	389.92	59.0	443.20	64.0	498.78	59.0	556.74	74.0	617.29
.1	390.96	.1	444.29	.1	499.92	.1	557.92	.1	618.53
.2	392.01	.2	445.38	.2	501.06	.2	559.10	.2	619.77
.3	393.06	.3	446.47	.3	502.20	.3	560.29	.3	621.01
.4	394.11	.4	447.56	.4	503.34	.4	561.48	.4	622.25
.5	395.16	.5	448.65	.5	504.48	.5	562.67	.5	623.49
.6	396.21	.6	449.74	.6	505.62	.6	563.86	.6	624.73
.7	397.26	.7	450.83	.7	506.76	.7	565.05	.7	625.98
.8	398.31	.8	451.92	.8	507.90	.8	566.25	.8	627.23
.9	399.36	.9	453.01	.9	509.04	.9	567.45	.9	628.48
55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65	75.0	629.73

TABLE 1.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	629.73	80.0	693.50	85.0	760.69	90.0	832.76	95.0	911.46
.1	630.98	.1	694.81	.1	762.08	.1	834.26	.1	913.12
.2	632.23	.2	696.12	.2	763.47	.2	835.76	.2	914.78
.3	633.48	.3	697.43	.3	764.86	.3	837.27	.3	916.44
.4	634.73	.4	698.74	.4	766.25	.4	838.78	.4	918.11
.5	635.98	.5	700.06	.5	767.65	.5	840.29	.5	919.79
.6	637.23	.6	701.38	.6	769.05	.6	841.80	.6	921.47
.7	638.48	.7	702.70	.7	770.45	.7	843.32	.7	923.16
.8	639.73	.8	704.02	.8	771.85	.8	844.84	.8	924.85
.9	640.98	.9	705.34	.9	773.25	.9	846.37	.9	926.54
76.0	642.23	81.0	706.66	86.0	774.66	91.0	847.90	96.0	928.24
.1	643.48	.1	707.98	.1	776.07	.1	849.43	.1	929.94
.2	644.73	.2	709.30	.2	777.48	.2	850.96	.2	931.64
.3	645.99	.3	710.62	.3	778.89	.3	852.50	.3	933.35
.4	647.25	.4	711.95	.4	780.30	.4	854.04	.4	935.06
.5	648.51	.5	713.28	.5	781.72	.5	855.58	.5	936.78
.6	649.77	.6	714.61	.6	783.14	.6	857.12	.6	938.50
.7	651.03	.7	715.94	.7	784.56	.7	858.67	.7	940.22
.8	652.29	.8	717.27	.8	785.98	.8	860.22	.8	941.95
.9	653.55	.9	718.60	.9	787.40	.9	861.77	.9	943.68
77.0	654.81	82.0	719.94	87.0	788.83	92.0	863.33	97.0	945.42
.1	656.08	.1	721.28	.1	790.26	.1	864.89	.1	947.17
.2	657.35	.2	722.62	.2	791.70	.2	866.46	.2	948.92
.3	658.62	.3	723.96	.3	793.14	.3	868.03	.3	950.68
.4	659.90	.4	725.30	.4	794.58	.4	869.61	.4	952.44
.5	661.18	.5	726.64	.5	796.02	.5	871.19	.5	954.21
.6	662.46	.6	727.98	.6	797.46	.6	872.77	.6	955.98
.7	663.74	.7	729.32	.7	798.91	.7	874.35	.7	957.76
.8	665.02	.8	730.66	.8	800.36	.8	875.93	.8	959.55
.9	666.30	.9	732.00	.9	801.81	.9	877.52	.9	961.34
78.0	667.58	83.0	733.35	88.0	803.26	93.0	879.11	98.0	963.14
.1	668.86	.1	734.70	.1	804.71	.1	880.70	.1	964.94
.2	670.14	.2	736.05	.2	806.16	.2	882.29	.2	966.75
.3	671.43	.3	737.40	.3	807.61	.3	883.88	.3	968.56
.4	672.72	.4	738.76	.4	809.07	.4	885.48	.4	970.38
.5	674.01	.5	740.12	.5	810.53	.5	887.08	.5	972.20
.6	675.30	.6	741.48	.6	811.99	.6	888.68	.6	974.02
.7	676.59	.7	742.84	.7	813.45	.7	890.29	.7	975.85
.8	677.88	.8	744.20	.8	814.92	.8	891.90	.8	977.58
.9	679.17	.9	745.56	.9	816.39	.9	893.51	.9	979.51
79.0	680.47	84.0	746.92	89.0	817.86	94.0	895.12	99.0	981.35
.1	681.77	.1	748.29	.1	819.34	.1	896.74	.1	983.19
.2	683.07	.2	749.66	.2	820.82	.2	898.36	.2	985.03
.3	684.37	.3	751.03	.3	822.30	.3	899.98	.3	986.88
.4	685.67	.4	752.40	.4	823.79	.4	901.61	.4	988.74
.5	686.97	.5	753.78	.5	825.28	.5	903.24	.5	990.60
.6	688.27	.6	755.16	.6	826.77	.6	904.88	.6	992.47
.7	689.57	.7	756.54	.7	828.26	.7	906.52	.7	994.35
.8	690.88	.8	757.92	.8	829.76	.8	908.16	.8	996.23
.9	692.19	.9	759.30	.9	831.26	.9	909.81	.9	998.11
80.0	693.50	85.0	760.69	90.0	832.76	95.0	911.46	100.0	1,000.00

TABLE 2.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F

[Total length of scale 1000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
0.0	0.00	5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90
.1	0.58	.1	28.37	.1	52.76	.1	74.89	.1	95.30
.2	1.16	.2	28.90	.2	53.22	.2	75.31	.2	95.70
.3	1.73	.3	29.43	.3	53.68	.3	75.73	.3	96.10
.4	2.31	.4	29.96	.4	54.14	.4	76.15	.4	96.50
.5	2.89	.5	30.48	.5	54.60	.5	76.57	.5	96.90
.6	3.47	.6	31.00	.6	55.06	.6	76.99	.6	97.30
.7	4.04	.7	31.51	.7	55.52	.7	77.41	.7	97.70
.8	4.62	.8	32.02	.8	55.98	.8	77.83	.8	98.11
.9	5.20	.9	32.53	.9	56.44	.9	78.25	.9	98.51
1.0	5.78	6.0	33.04	11.0	56.90	16.0	78.67	21.0	98.92
.1	6.36	.1	33.55	.1	57.36	.1	79.09	.1	99.33
.2	6.93	.2	34.05	.2	57.82	.2	79.51	.2	99.74
.3	7.50	.3	34.55	.3	58.28	.3	79.93	.3	100.15
.4	8.07	.4	35.05	.4	58.74	.4	80.35	.4	100.56
.5	8.64	.5	35.55	.5	59.20	.5	80.77	.5	100.97
.6	9.21	.6	36.05	.6	59.65	.6	81.19	.6	101.38
.7	9.78	.7	36.55	.7	60.10	.7	81.60	.7	101.79
.8	10.35	.8	37.05	.8	60.55	.8	82.01	.8	102.20
.9	10.92	.9	37.55	.9	61.00	.9	82.42	.9	102.61
2.0	11.49	7.0	38.05	12.0	61.45	17.0	82.83	22.0	103.02
.1	12.05	.1	38.54	.1	61.90	.1	83.24	.1	103.43
.2	12.61	.2	39.03	.2	62.35	.2	83.65	.2	103.84
.3	13.17	.3	39.52	.3	62.79	.3	84.06	.3	104.25
.4	13.73	.4	40.01	.4	63.23	.4	84.47	.4	104.66
.5	14.29	.5	40.50	.5	63.67	.5	84.88	.5	105.08
.6	14.85	.6	40.98	.6	64.11	.6	85.28	.6	105.50
.7	15.41	.7	41.46	.7	64.55	.7	85.69	.7	105.92
.8	15.97	.8	41.94	.8	64.99	.8	86.09	.8	106.34
.9	16.52	.9	42.42	.9	65.43	.9	86.49	.9	106.76
3.0	17.07	8.0	42.89	13.0	65.87	18.0	86.89	23.0	107.18
.1	17.62	.1	43.36	.1	66.31	.1	87.29	.1	107.60
.2	18.17	.2	43.83	.2	66.74	.2	87.69	.2	108.02
.3	18.72	.3	44.30	.3	67.17	.3	88.09	.3	108.44
.4	19.27	.4	44.77	.4	67.60	.4	88.50	.4	108.86
.5	19.82	.5	45.24	.5	68.03	.5	88.90	.5	109.28
.6	20.37	.6	45.72	.6	68.46	.6	89.30	.6	109.70
.7	20.91	.7	46.20	.7	68.89	.7	89.70	.7	110.12
.8	21.45	.8	46.67	.8	69.32	.8	90.10	.8	110.54
.9	21.99	.9	47.14	.9	69.75	.9	90.50	.9	110.96
4.0	22.53	9.0	47.61	14.0	70.18	19.0	90.90	24.0	111.38
.1	23.07	.1	48.08	.1	70.61	.1	91.30	.1	111.81
.2	23.60	.2	48.55	.2	71.04	.2	91.70	.2	112.24
.3	24.13	.3	49.02	.3	71.47	.3	92.10	.3	112.67
.4	24.66	.4	49.49	.4	71.90	.4	92.50	.4	113.10
.5	25.19	.5	49.96	.5	72.33	.5	92.90	.5	113.53
.6	25.72	.6	50.43	.6	72.76	.6	93.30	.6	113.96
.7	26.25	.7	50.90	.7	73.19	.7	93.70	.7	114.39
.8	26.78	.8	51.37	.8	73.62	.8	94.10	.8	114.82
.9	27.31	.9	51.84	.9	74.05	.9	94.50	.9	115.25
5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90	25.0	115.66

TABLE 2.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	115.68	30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59
.1	116.11	.1	138.75	.1	164.92	.1	195.79	.1	231.35
.2	116.54	.2	139.23	.2	165.49	.2	196.46	.2	232.11
.3	116.97	.3	139.71	.3	166.06	.3	197.13	.3	232.87
.4	117.40	.4	140.20	.4	166.63	.4	197.80	.4	233.63
.5	117.83	.5	140.69	.5	167.20	.5	198.47	.5	234.39
.6	118.27	.6	141.18	.6	167.78	.6	199.14	.6	235.16
.7	118.71	.7	141.67	.7	168.36	.7	199.82	.7	235.93
.8	119.15	.8	142.16	.8	168.94	.8	200.50	.8	236.71
.9	119.59	.9	142.65	.9	169.53	.9	201.18	.9	237.49
26.0	120.03	31.0	143.14	36.0	170.12	41.0	201.86	46.0	238.28
.1	120.47	.1	143.63	.1	170.71	.1	202.55	.1	239.06
.2	120.91	.2	144.12	.2	171.30	.2	203.24	.2	239.84
.3	121.35	.3	144.61	.3	171.89	.3	203.93	.3	240.62
.4	121.79	.4	145.10	.4	172.48	.4	204.62	.4	241.40
.5	122.23	.5	145.59	.5	173.08	.5	205.31	.5	242.18
.6	122.67	.6	146.09	.6	173.68	.6	206.00	.6	242.97
.7	123.12	.7	146.59	.7	174.28	.7	206.70	.7	243.76
.8	123.57	.8	147.11	.8	174.88	.8	207.40	.8	244.55
.9	124.02	.9	147.63	.9	175.48	.9	208.10	.9	245.34
27.0	124.47	32.0	148.15	37.0	176.08	42.0	208.80	47.0	246.14
.1	124.92	.1	148.67	.1	176.69	.1	209.50	.1	246.94
.2	125.37	.2	149.19	.2	177.30	.2	210.20	.2	247.74
.3	125.82	.3	149.71	.3	177.91	.3	210.90	.3	248.54
.4	126.27	.4	150.23	.4	178.52	.4	211.60	.4	249.35
.5	126.72	.5	150.75	.5	179.13	.5	212.31	.5	250.16
.6	127.17	.6	151.27	.6	179.75	.6	213.02	.6	250.97
.7	127.62	.7	151.79	.7	180.37	.7	213.73	.7	251.79
.8	128.07	.8	152.31	.8	180.99	.8	214.44	.8	252.61
.9	128.52	.9	152.84	.9	181.62	.9	215.15	.9	253.43
28.0	128.98	33.0	153.37	38.0	182.25	43.0	215.87	48.0	254.25
.1	129.44	.1	153.90	.1	182.88	.1	216.59	.1	255.07
.2	129.90	.2	154.43	.2	183.51	.2	217.31	.2	255.89
.3	130.36	.3	154.96	.3	184.14	.3	218.03	.3	256.71
.4	130.82	.4	155.50	.4	184.77	.4	218.75	.4	257.53
.5	131.28	.5	156.04	.5	185.40	.5	219.48	.5	258.36
.6	131.74	.6	156.58	.6	186.03	.6	220.21	.6	259.19
.7	132.20	.7	157.12	.7	186.67	.7	220.94	.7	260.02
.8	132.66	.8	157.66	.8	187.31	.8	221.67	.8	260.85
.9	133.12	.9	158.21	.9	187.95	.9	222.40	.9	261.69
29.0	133.58	34.0	158.76	39.0	188.59	44.0	223.14	49.0	262.53
.1	134.04	.1	159.31	.1	189.23	.1	223.88	.1	263.37
.2	134.51	.2	159.86	.2	189.88	.2	224.62	.2	264.21
.3	134.98	.3	160.42	.3	190.53	.3	225.36	.3	265.05
.4	135.45	.4	160.98	.4	191.18	.4	226.10	.4	265.89
.5	135.92	.5	161.54	.5	191.83	.5	226.84	.5	266.74
.6	136.39	.6	162.10	.6	192.48	.6	227.59	.6	267.59
.7	136.86	.7	162.66	.7	193.13	.7	228.34	.7	268.44
.8	137.33	.8	163.22	.8	193.79	.8	229.09	.8	269.30
.9	137.80	.9	163.78	.9	194.45	.9	229.84	.9	270.16
30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59	50.0	271.02

TABLE 2.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
50.0	271.02	55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10
.1	271.88	.1	316.88	.1	366.04	.1	419.50	.1	477.31
.2	272.74	.2	317.82	.2	367.07	.2	420.60	.2	478.52
.3	273.60	.3	318.76	.3	368.10	.3	421.71	.3	479.73
.4	274.47	.4	319.70	.4	369.13	.4	422.82	.4	480.94
.5	275.34	.5	320.65	.5	370.16	.5	423.93	.5	482.15
.6	276.21	.6	321.60	.6	371.20	.6	425.05	.6	483.36
.7	277.08	.7	322.55	.7	372.24	.7	426.17	.7	484.57
.8	277.95	.8	323.50	.8	373.28	.8	427.29	.8	485.78
.9	278.82	.9	324.45	.9	374.32	.9	428.41	.9	487.00
51.0	279.70	56.0	325.40	61.0	375.36	66.0	429.54	71.0	488.22
.1	280.58	.1	326.35	.1	376.40	.1	430.67	.1	489.45
.2	281.46	.2	327.31	.2	377.44	.2	431.80	.2	490.68
.3	282.34	.3	328.27	.3	378.49	.3	432.93	.3	491.91
.4	283.22	.4	329.23	.4	379.54	.4	434.06	.4	493.14
.5	284.10	.5	330.19	.5	380.60	.5	435.19	.5	494.37
.6	284.98	.6	331.15	.6	381.66	.6	436.32	.6	495.60
.7	285.87	.7	332.11	.7	382.72	.7	437.46	.7	496.84
.8	286.76	.8	333.07	.8	383.78	.8	438.60	.8	498.08
.9	287.65	.9	334.03	.9	384.84	.9	439.75	.9	499.32
52.0	288.54	57.0	334.99	62.0	385.91	67.0	440.90	72.0	500.56
.1	289.43	.1	335.95	.1	386.98	.1	442.05	.1	501.80
.2	290.32	.2	336.92	.2	388.05	.2	443.20	.2	503.05
.3	291.21	.3	337.89	.3	389.12	.3	444.35	.3	504.30
.4	292.10	.4	338.87	.4	390.19	.4	445.50	.4	505.56
.5	292.99	.5	339.85	.5	391.26	.5	446.65	.5	506.82
.6	293.89	.6	340.83	.6	392.33	.6	447.80	.6	508.08
.7	294.79	.7	341.81	.7	393.40	.7	448.95	.7	509.34
.8	295.69	.8	342.79	.8	394.47	.8	450.11	.8	510.60
.9	296.59	.9	343.78	.9	395.55	.9	451.26	.9	511.86
53.0	297.50	58.0	344.78	63.0	396.63	68.0	452.42	73.0	513.13
.1	298.41	.1	345.78	.1	397.71	.1	453.58	.1	514.40
.2	299.32	.2	346.78	.2	398.79	.2	454.74	.2	515.67
.3	300.23	.3	347.78	.3	399.87	.3	455.91	.3	516.94
.4	301.14	.4	348.78	.4	400.95	.4	457.08	.4	518.21
.5	302.05	.5	349.78	.5	402.03	.5	458.25	.5	519.48
.6	302.96	.6	350.78	.6	403.11	.6	459.43	.6	520.76
.7	303.87	.7	351.78	.7	404.19	.7	460.61	.7	522.04
.8	304.78	.8	352.78	.8	405.27	.8	461.79	.8	523.32
.9	305.70	.9	353.79	.9	406.36	.9	462.98	.9	524.60
54.0	306.62	59.0	354.80	64.0	407.45	69.0	464.17	74.0	525.89
.1	307.55	.1	355.81	.1	408.54	.1	465.36	.1	527.18
.2	308.48	.2	356.82	.2	409.63	.2	466.55	.2	528.47
.3	309.41	.3	357.84	.3	410.72	.3	467.74	.3	529.76
.4	310.34	.4	358.86	.4	411.81	.4	468.93	.4	531.05
.5	311.27	.5	359.88	.5	412.90	.5	470.12	.5	532.34
.6	312.20	.6	360.90	.6	414.00	.6	471.31	.6	533.63
.7	313.13	.7	361.92	.7	415.10	.7	472.50	.7	534.92
.8	314.06	.8	362.95	.8	416.20	.8	473.70	.8	536.21
.9	315.00	.9	363.98	.9	417.30	.9	474.90	.9	537.51
55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10	75.0	538.81

TABLE 2.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	538.81	80.0	607.33	85.0	682.71	90.0	767.67	95.0	868.34
.1	540.12	.1	608.77	.1	684.31	.1	769.50	.1	870.60
.2	541.43	.2	610.21	.2	685.91	.2	771.33	.2	872.87
.3	542.74	.3	611.65	.3	687.52	.3	773.16	.3	875.15
.4	544.05	.4	613.09	.4	689.13	.4	774.99	.4	877.44
.5	545.37	.5	614.53	.5	690.74	.5	776.83	.5	879.74
.6	546.69	.6	615.97	.6	692.36	.6	778.68	.6	882.05
.7	548.01	.7	617.42	.7	693.98	.7	780.54	.7	884.37
.8	549.33	.8	618.87	.8	695.60	.8	782.41	.8	886.71
.9	550.66	.9	620.33	.9	697.23	.9	784.29	.9	889.06
76.0	552.00	81.0	621.79	86.0	698.86	91.0	786.18	96.0	891.43
.1	553.34	.1	623.26	.1	700.50	.1	788.08	.1	893.82
.2	554.68	.2	624.73	.2	702.14	.2	789.98	.2	896.22
.3	556.02	.3	626.20	.3	703.79	.3	791.88	.3	898.62
.4	557.36	.4	627.67	.4	705.44	.4	793.78	.4	901.03
.5	558.70	.5	629.14	.5	707.10	.5	795.69	.5	903.45
.6	560.05	.6	630.62	.6	708.76	.6	797.62	.6	905.89
.7	561.40	.7	632.10	.7	710.42	.7	799.57	.7	908.34
.8	562.75	.8	633.58	.8	712.08	.8	801.52	.8	910.80
.9	564.10	.9	635.07	.9	713.74	.9	803.49	.9	913.27
77.0	565.45	82.0	636.56	87.0	715.41	92.0	805.46	97.0	915.75
.1	566.81	.1	638.05	.1	717.08	.1	807.44	.1	918.25
.2	568.17	.2	639.54	.2	718.75	.2	809.42	.2	920.77
.3	569.53	.3	641.03	.3	720.43	.3	811.40	.3	923.31
.4	570.89	.4	642.53	.4	722.11	.4	813.39	.4	925.88
.5	572.25	.5	644.03	.5	723.80	.5	815.38	.5	928.46
.6	573.62	.6	645.54	.6	725.50	.6	817.38	.6	931.05
.7	574.99	.7	647.05	.7	727.20	.7	819.40	.7	933.66
.8	576.37	.8	648.57	.8	728.90	.8	821.42	.8	936.28
.9	577.75	.9	650.09	.9	730.60	.9	823.45	.9	938.93
78.0	579.13	83.0	651.61	88.0	732.31	93.0	825.49	98.0	941.61
.1	580.52	.1	653.13	.1	734.02	.1	827.54	.1	944.33
.2	581.92	.2	654.65	.2	735.74	.2	829.60	.2	947.06
.3	583.32	.3	656.18	.3	737.46	.3	831.67	.3	949.80
.4	584.72	.4	657.71	.4	739.19	.4	833.74	.4	952.56
.5	586.12	.5	659.24	.5	740.93	.5	835.82	.5	955.35
.6	587.52	.6	660.77	.6	742.68	.6	837.90	.6	958.16
.7	588.92	.7	662.31	.7	744.43	.7	840.00	.7	961.00
.8	590.32	.8	663.85	.8	746.19	.8	842.12	.8	963.86
.9	591.72	.9	665.40	.9	747.95	.9	844.25	.9	966.74
79.0	593.12	84.0	666.96	89.0	749.72	94.0	846.40	99.0	969.64
.1	594.53	.1	668.52	.1	751.49	.1	848.56	.1	972.56
.2	595.94	.2	670.08	.2	753.27	.2	850.73	.2	975.52
.3	597.35	.3	671.64	.3	755.05	.3	852.90	.3	978.50
.4	598.77	.4	673.21	.4	756.84	.4	855.08	.4	981.50
.5	600.19	.5	674.79	.5	758.64	.5	857.26	.5	984.52
.6	601.61	.6	676.37	.6	760.45	.6	859.46	.6	987.55
.7	603.04	.7	677.95	.7	762.25	.7	861.67	.7	990.61
.8	604.47	.8	679.53	.8	764.05	.8	863.88	.8	993.71
.9	605.90	.9	681.12	.9	765.86	.9	866.10	.9	996.84
80.0	607.33	85.0	682.71	90.0	767.67	95.0	868.34	100.0	1,000.00

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No. 19

STANDARD DENSITY AND VOLUMETRIC TABLES

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STANDARD DENSITY AND VOLUMETRIC TABLES

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INTRODUCTION

The wide application of hydrometers as measuring instruments in the collection of revenues in commerce and in the industries makes it very important to define the various scales of indication of these instruments in terms of fundamental units.

The confusion and discordance heretofore resulting from the use of various insufficiently defined hydrometer scales, and the lack of opportunity for verifying standards on a uniform basis, led the Bureau to investigate the problems connected with hydrometry and to prepare standard density tables for definition of hydrometer scales.

In Bureau Circular No. 16 the conditions are announced under which the testing of hydrometers will be conducted, and specifications are given as to the construction, standardization, and accuracy required for hydrometers in order that they be approved as precision instruments.

The present circular comprises the density tables which have been adopted for definition of hydrometer scales, auxiliary tables which have been prepared for reduction of hydrometer readings, tables for computation of volumetric capacity, and others of similar nature giving physical constants for which the Bureau receives frequent inquiries.

In all tables found in this circular the term DENSITY is used to represent the MASS per UNIT VOLUME and is expressed in GRAMS per MILLILITER.

The term SPECIFIC GRAVITY is used to express the RELATIVE MASSES of EQUAL VOLUMES of the liquid in question and of water, EACH LIQUID being at a DEFINITELY STATED TEMPERATURE. For example, specific gravity at $\frac{60^\circ}{60^\circ}\text{F}$ means the specific gravity of the liquid at 60°F referred to water at 60°F as unity.

The density values in Tables 1, 2, 8, 12, 13, 26, and 27 are numerically the same as specific gravities at the various temperatures referred to water at 4°C as unity.

For the sake of uniformity the same abbreviation, D, with the proper temperature basis, is used for both density and specific gravity.

S. W. STRATTON,
Director.

Approved:

WILLIAM C. REDFIELD,
Secretary.

TABLE 1.—Density² (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water^{2a}

Per cent alcohol by weight	Temperature						
	10° C	15° C	20° C	25° C	30° C	35° C	40° C
0	0.99973	0.99913	0.99823	0.99708	0.99568	0.99406	0.99225
1	785	725	636	520	379	217	034
2	602	542	453	336	194	031	.98846
3	426	365	275	157	014	.98849	663
4	258	195	103	.98984	.98839	672	485
5	098	032	.98938	817	670	501	311
6	.98946	.98877	780	656	507	335	142
7	801	729	627	500	347	172	.97975
8	660	584	478	346	189	009	808
9	524	442	331	193	031	.97846	641
10	393	304	187	043	.97875	685	475
11	267	171	047	.97897	723	527	312
12	145	041	.97910	753	573	371	150
13	026	.97914	775	611	424	216	.96989
14	.97911	790	643	472	278	063	829
15	800	669	514	334	133	.96911	670
16	692	552	387	199	.96990	760	512
17	583	433	259	062	844	607	352
18	473	313	129	.96923	697	452	189
19	363	191	.96997	782	547	294	023
20	252	068	864	639	395	134	.95856
21	139	.96944	729	495	242	.95973	687
22	024	818	592	348	087	809	516
23	.96907	689	453	199	.95929	643	343
24	787	558	312	048	769	476	168
25	665	424	168	.95895	607	306	.94991
26	539	287	020	738	442	133	810
27	406	144	.95867	576	272	.94955	625
28	268	.95996	710	410	098	774	438
29	125	844	548	241	.94922	590	248
30	.95977	686	382	067	741	403	055
31	823	524	212	.94890	557	214	.93860
32	665	357	038	709	370	021	662
33	502	186	.94860	525	180	.93825	461
34	334	011	679	337	.93986	626	257
35	162	.94832	494	146	790	425	051
36	.94986	650	306	.93952	591	221	.92843
37	805	464	114	756	390	016	634
38	620	273	.93919	556	186	.92808	422
39	431	079	720	353	.92979	597	208
40	238	.93882	518	148	770	385	.91992
41	042	682	314	.92940	558	170	774
42	.98842	478	107	729	344	.91952	554
43	639	271	.92897	516	128	733	332
44	433	062	685	301	.91910	513	108
45	226	.92852	472	085	692	291	.90884
46	017	640	257	.91868	472	069	660
47	.92806	426	041	649	250	.90845	434
48	593	211	.91823	429	028	621	207
49	379	.91995	604	208	.90805	396	.89979
50	162	776	384	.90985	580	168	750

² The density values given in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4° C of unity.

^{2a} Tables 1, 2, 3, 4, 5, 6, and 7 of this circular are based on the work done at this Bureau and published in the Bulletin of the Bureau of Standards, vol. 9, No. 3. (Reprint No. 197.)

TABLE 1.—Density (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water—Continued

Per cent alcohol by weight	Temperature						
	10° C	15° C	20° C	25° C	30° C	35° C	40° C
50	0.92162	0.91776	0.91384	0.90985	0.90580	0.90168	0.89750
51	.91943	.555	.160	.760	.353	.89940	.519
52	.723	.333	.90936	.534	.125	.710	.288
53	.502	.110	.711	.307	.89896	.479	.056
54	.279	.90885	.485	.079	.667	.248	.88823
55	.055	.659	.258	.89850	.437	.016	.589
56	.90831	.433	.031	.621	.206	.88784	.356
57	.607	.207	.89803	.392	.89975	.552	.122
58	.381	.89980	.574	.162	.744	.319	.87888
59	.154	.752	.344	.88931	.512	.085	.653
60	.89927	.523	.113	.699	.278	.87851	.417
61	.698	.293	.88882	.466	.044	.615	.180
62	.468	.062	.650	.233	.87809	.379	.86943
63	.237	.88830	.417	.87998	.574	.142	.705
64	.006	.597	.183	.763	.337	.86905	.466
65	.88774	.364	.87948	.527	.100	.667	.227
66	.541	.130	.713	.291	.86863	.429	.85987
67	.308	.87895	.477	.054	.625	.190	.747
68	.074	.660	.241	.86817	.387	.85950	.507
69	.87839	.424	.004	.579	.148	.710	.266
70	.602	.187	.86766	.340	.85908	.470	.025
71	.365	.86949	.527	.100	.667	.228	.84783
72	.127	.710	.287	.85859	.426	.84986	.540
73	.86888	.470	.047	.618	.184	.743	.297
74	.648	.229	.85806	.376	.84941	.500	.053
75	.408	.85988	.564	.134	.698	.257	.83809
76	.168	.747	.322	.84891	.455	.013	.564
77	.85927	.505	.079	.647	.211	.83768	.319
78	.685	.84835	.403	.83966	.523	.074	.81828
79	.442	.018	.590	.158	.720	.277	.82827
80	.197	.84772	.344	.83911	.473	.029	.578
81	.84950	.525	.096	.664	.224	.82780	.329
82	.702	.277	.83848	.415	.82974	.530	.079
83	.453	.028	.599	.164	.724	.279	.81828
84	.203	.83777	.348	.82913	.473	.027	.576
85	.83951	.525	.095	.660	.220	.81774	.322
86	.697	.271	.82840	.405	.81965	.519	.067
87	.441	.014	.583	.148	.708	.262	.80811
88	.181	.82754	.323	.81888	.448	.003	.552
89	.82919	.492	.062	.626	.186	.80742	.291
90	.654	.227	.81797	.362	.80922	.478	.028
91	.386	.81959	.529	.094	.655	.211	.79761
92	.114	.688	.257	.80823	.384	.79941	.491
93	.81839	.413	.80983	.549	.111	.669	.220
94	.561	.134	.705	.272	.79835	.398	.78947
95	.278	.80852	.424	.79991	.555	.114	.670
96	.80991	.566	.138	.706	.271	.78831	.388
97	.698	.274	.79846	.415	.78981	.542	.100
98	.399	.79975	.547	.117	.684	.247	.77806
99	.094	.670	.243	.78814	.382	.77946	.507
100	.79784	.360	.78934	.506	.075	.641	.203

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TABLE 2.—Density^{2b} (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water at 20° C

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.99823	804	785	766	748	729	710	692	673	655
1	636	618	599	581	562	544	525	507	489	471
2	453	435	417	399	381	363	345	327	310	292
3	275	257	240	222	205	188	171	154	137	120
4	103	087	070	053	037	020	003	*987	*971	*954
5	.98938	922	906	890	874	859	843	827	811	796
6	780	765	749	734	718	703	688	673	658	642
7	627	612	597	582	567	553	538	523	508	493
8	478	463	449	434	419	404	389	374	360	345
9	331	316	301	287	273	258	244	229	215	201
10	187	172	158	144	130	117	103	089	075	061
11	047	033	019	006	*992	*978	*964	*951	*937	*923
12	.97910	896	883	869	855	842	828	815	801	788
13	775	761	748	735	722	709	696	683	670	657
14	643	630	617	604	591	578	565	552	539	526
15	514	501	488	475	462	450	438	425	412	400
16	387	374	361	349	336	323	310	297	284	272
17	259	246	233	220	207	194	181	168	155	142
18	129	116	103	089	076	063	050	037	024	010
19	.96997	984	971	957	944	931	917	904	891	877
20	864	850	837	823	810	796	783	769	756	742
21	729	716	702	688	675	661	647	634	620	606
22	592	578	564	551	537	523	509	495	481	467
23	453	439	425	411	396	382	368	354	340	326
24	312	297	283	269	254	240	225	211	196	182
25	168	153	139	124	109	094	080	065	050	035
26	020	005	*990	*975	*959	*944	*929	*914	*898	*883
27	.95867	851	836	820	805	789	773	757	742	726
28	710	694	678	662	646	630	613	597	581	565
29	548	532	516	499	483	466	450	433	416	400
30	382	365	349	332	315	298	281	264	247	230
31	212	195	178	161	143	126	108	091	074	056
32	038	020	003	*985	*967	*950	*932	*914	*896	*878
33	.94860	842	824	806	788	770	752	734	715	697
34	679	660	642	624	605	587	568	550	531	512
35	494	475	456	438	419	400	382	363	344	325
36	306	287	268	249	230	211	192	172	153	134
37	114	095	075	056	036	017	*997	*978	*958	*939
38	.93919	899	879	859	840	820	800	780	760	740
39	720	700	680	660	640	620	599	579	559	539
40	518	498	478	458	437	417	396	376	356	335
41	314	294	273	253	232	212	191	170	149	129
42	107	086	065	044	023	002	*981	*960	*939	*918
43	.92897	876	855	834	812	791	770	749	728	707
44	685	664	642	621	600	579	557	536	515	493
45	472	450	429	408	386	365	343	322	300	279
46	257	236	214	193	171	150	128	106	085	063
47	041	019	*997	*976	*954	*932	*910	*889	*867	*845
48	.91823	801	780	758	736	714	692	670	648	626
49	604	582	560	538	516	494	472	450	428	406
50	384	361	339	317	295	272	250	228	206	183

^{2b} The density values given in this table are numerically the same as specific gravity at 20° C in terms of water at 4° C as unity.

TABLE 2.—Density (in grams per milliliter) of Mixtures of Ethyl Alcohol and Water, at 20° C—Continued

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	0.91384	361	339	317	295	272	250	228	206	183
51	160	138	116	093	071	049	026	004	*981	*959
52	.90936	914	891	869	846	824	801	779	756	734
53	711	689	666	644	621	598	576	553	531	508
54	485	463	440	417	395	372	349	327	304	281
55	258	236	213	190	167	145	122	099	076	054
56	031	008	*985	*962	*939	*917	*894	*871	*848	*825
57	.89803	780	757	734	711	688	665	643	620	597
58	574	551	528	505	482	459	436	413	390	367
59	344	321	298	275	252	229	206	183	160	137
60	113	090	067	044	021	*998	*975	*951	*928	*905
61	.88882	859	836	812	789	766	743	720	696	673
62	650	626	603	580	557	533	510	487	463	440
63	417	393	370	347	323	300	277	253	230	206
64	183	160	136	113	089	066	042	019	*995	*972
65	.87948	925	901	878	854	831	807	784	760	737
66	713	689	666	642	619	595	572	548	524	501
67	477	454	430	406	383	359	336	312	288	265
68	241	218	194	170	147	123	099	075	052	028
69	004	*981	*957	*933	*909	*885	*862	*838	*814	*790
70	.86766	742	718	694	671	647	623	599	575	551
71	527	503	479	455	431	407	383	359	335	311
72	287	263	239	215	191	167	143	119	095	071
73	047	022	*998	*974	*950	*926	*902	*878	*854	*830
74	.85806	781	757	733	709	685	661	636	612	588
75	564	540	515	491	467	443	419	394	370	346
76	322	297	273	249	225	200	176	152	128	103
77	079	055	031	006	*982	*958	*933	*909	*884	*860
78	.84835	811	787	762	738	713	689	664	640	615
79	590	566	541	517	492	467	443	418	393	369
80	344	319	294	270	245	220	196	171	146	121
81	096	072	047	022	*997	*972	*947	*923	*898	*873
82	.83848	823	798	773	748	723	698	674	649	624
83	599	574	549	523	498	473	448	423	398	373
84	348	323	297	272	247	222	196	171	146	120
85	095	070	044	019	*994	*968	*943	*917	*892	*866
86	.82840	815	789	763	738	712	686	660	635	609
87	583	557	531	505	479	453	427	401	375	349
88	323	297	271	245	219	193	167	140	114	088
89	062	035	009	*983	*956	*930	*903	*877	*850	*824
90	.81797	770	744	717	690	664	637	610	583	556
91	529	502	475	448	421	394	366	339	312	285
92	257	230	203	175	148	120	093	066	038	010
93	.80983	955	928	900	872	844	817	789	761	733
94	705	677	649	621	593	565	537	509	480	452
95	424	395	367	338	310	281	253	224	195	166
96	138	109	080	051	022	*993	*963	*934	*905	*875
97	.79846	816	787	757	727	698	668	638	608	578
98	547	517	487	456	426	396	365	335	305	274
99	243	213	182	151	120	089	059	028	*997	*966
100	.78934									

TABLE 3.—Specific Gravity at 60° F (15.56° C) of Mixtures (by Volume) of Ethyl Alcohol and Water

Per Cent Alcohol by Volume at 60° F	Tenths of Per Cent									
	0.	1	2	3	4	5	6	7	8	9
0	1.00000	^{*985}	^{*970}	^{*955}	^{*940}	^{*925}	^{*910}	^{*895}	^{*880}	^{*865}
1	.99850	835	820	806	791	776	761	747	732	717
2	703	688	674	659	645	630	616	602	587	573
3	559	545	531	516	502	488	474	460	446	432
4	419	405	391	378	364	350	336	323	309	296
5	282	269	255	242	228	215	202	189	176	163
6	150	137	124	111	098	085	073	060	047	035
7	022	009	^{*997}	^{*984}	^{*972}	^{*960}	^{*947}	^{*935}	^{*923}	^{*911}
8	^{.98899}	887	875	863	851	838	826	814	803	791
9	779	767	755	743	731	720	708	696	684	672
10	661	649	637	625	614	602	590	579	567	556
11	544	532	521	509	498	487	475	464	452	441
12	430	419	408	396	385	374	363	352	341	330
13	319	308	297	286	275	264	254	243	232	221
14	210	200	190	179	168	157	147	136	125	115
15	104	093	083	072	062	051	040	030	019	009
16	^{.97998}	988	977	967	956	946	936	925	915	905
17	895	885	875	864	854	844	834	824	814	804
18	794	784	774	764	754	744	734	724	714	704
19	694	684	674	664	654	645	635	625	615	605
20	596	586	576	566	556	546	536	526	516	506
21	496	486	476	466	456	446	436	425	415	405
22	395	385	375	365	354	344	334	324	313	303
23	293	283	272	262	252	241	231	221	210	200
24	189	179	168	158	147	137	126	116	105	095
25	084	073	063	052	042	031	020	010	^{*999}	^{*988}
26	^{.96978}	967	957	946	935	924	914	903	892	881
27	870	859	848	837	826	815	804	793	782	771
28	760	749	738	727	715	704	693	682	671	659
29	648	637	625	614	603	591	580	568	557	546
30	534	522	511	499	488	476	464	453	441	429
31	418	406	394	382	370	358	346	334	321	309
32	296	284	271	259	246	234	221	209	196	183
33	170	157	144	132	119	106	093	080	067	054
34	041	028	015	002	^{*988}	^{*975}	^{*962}	^{*948}	^{*935}	^{*921}
35	^{.95908}	894	881	867	854	840	826	812	798	784
36	770	756	742	728	714	700	685	671	657	643
37	628	614	599	585	570	556	541	526	512	497
38	482	467	452	437	423	408	393	378	362	347
39	332	317	302	286	271	256	240	225	209	194
40	178	162	147	131	115	100	084	068	052	036
41	020	004	^{*988}	^{*972}	^{*956}	^{*940}	^{*923}	^{*907}	^{*891}	^{*875}
42	^{.94858}	842	825	809	792	776	759	743	726	710
43	693	676	660	643	626	609	592	575	558	541
44	524	507	490	473	455	438	421	403	386	369
45	351	334	316	298	281	263	245	228	210	192
46	174	156	138	120	102	084	066	048	030	011
47	^{.93993}	975	956	938	920	901	883	864	845	827
48	808	789	771	752	733	714	695	676	657	638
49	619	600	581	562	543	523	504	485	465	446
50	426	407	387	368	348	328	309	289	270	250

TABLE 3.—Specific Gravity at 60° F (15° 56 C) of Mixtures (by Volume) of Ethyl Alcohol and Water—Continued

Per Cent Alcohol by Volume at 60° F	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	.93426	407	387	368	348	328	309	289	270	250
51	230	210	190	171	151	131	111	091	071	051
52	031	011	*971	*951	*931	*911	*891	*870	*850	*830
53	.92830	810	789	769	749	728	708	688	667	647
54	626	605	585	564	544	523	502	482	461	440
55	419	398	377	357	336	315	294	273	252	231
56	210	189	168	147	126	105	084	062	041	020
57	.91999	978	956	935	914	892	871	849	827	806
58	784	762	741	719	697	675	653	631	610	588
59	565	543	521	499	477	455	433	410	388	366
60	344	322	299	277	255	232	210	188	165	143
61	120	097	075	052	030	007	*984	*962	*939	*916
62	.90893	870	847	825	802	779	756	733	710	687
63	664	641	618	595	572	549	526	503	480	457
64	434	411	388	365	341	318	295	272	249	225
65	202	179	155	132	108	085	061	038	014	*991
66	.89967	943	920	896	872	848	825	801	777	753
67	729	705	681	657	633	609	585	561	537	513
68	489	465	441	416	392	368	343	319	295	270
69	245	220	196	171	147	122	098	073	048	024
70	.88999	974	950	925	900	875	850	825	801	776
71	751	725	700	675	650	625	600	574	549	524
72	499	474	448	423	397	372	346	321	296	270
73	244	218	193	167	141	116	090	064	039	013
74	.87987	961	935	910	884	858	832	806	780	754
75	728	702	676	650	623	597	571	545	518	492
76	465	439	412	386	359	332	306	279	252	226
77	199	172	145	118	092	065	038	011	*984	*957
78	.86929	902	875	847	820	793	766	738	711	684
79	656	629	601	574	546	518	491	463	435	408
80	380	352	324	296	269	241	213	185	157	129
81	100	072	044	015	*987	*959	*931	*902	*874	*846
82	.85817	789	760	732	703	674	646	617	588	560
83	531	502	473	444	415	386	357	328	299	270
84	240	211	181	152	122	093	063	033	004	*974
85	.84944	914	884	854	824	794	764	734	703	673
86	642	612	581	551	520	490	459	428	398	367
87	336	303	274	243	212	181	150	119	088	056
88	025	*994	*962	*930	*899	*867	*835	*803	*771	*739
89	.83707	675	643	610	578	545	513	480	447	415
90	382	349	315	282	249	216	183	150	116	083
91	049	015	*981	*947	*913	*879	*845	*810	*776	*741
92	.82705	670	635	600	565	529	494	458	423	387
93	351	315	279	243	206	170	133	096	059	022
94	.81984	947	909	871	834	796	757	719	681	642
95	603	564	525	486	446	407	367	327	287	247
96	206	165	125	084	042	001	*960	*918	*876	*834
97	.80792	750	707	664	620	577	533	489	445	401
98	356	311	265	219	173	127	080	033	*985	*937
99	.79889	841	792	743	693	643	593	543	492	441
100	389									

TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which Tables 1, 2, 3, 5, 6, and 7 are calculated. The hydrometer is assumed to be of Jena 16^{III} glass. For the per cents not given between 40 and 80, linear interpolation of the tabulated corrections will give results sufficiently exact for most purposes.]

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume												
	0	1	2	3	4	5	6	7	8	9	10	11	12
	Add to Observed Per Cent Alcohol												
50	0.37	0.38	0.39	0.40	0.42	0.45	0.48	0.52	0.56	0.61	0.66	0.74	0.81
51	.34	.35	.36	.37	.39	.41	.44	.47	.51	.56	.61	.68	.75
52	.32	.32	.33	.34	.35	.38	.40	.43	.47	.51	.55	.62	.68
53	.29	.30	.30	.31	.32	.34	.36	.39	.42	.46	.49	.55	.60
54	.26	.26	.26	.27	.28	.29	.32	.34	.36	.40	.43	.48	.52
55	.22	.22	.23	.23	.24	.25	.27	.29	.31	.34	.37	.40	.44
56	.18	.18	.18	.18	.19	.20	.22	.24	.25	.28	.30	.33	.36
57	.14	.14	.14	.14	.14	.15	.17	.18	.19	.21	.23	.25	.27
58	.09	.10	.10	.10	.10	.10	.11	.12	.13	.14	.16	.18	.18
59	.05	.05	.05	.05	.05	.05	.06	.06	.06	.07	.08	.08	.09
	Subtract from Observed Per Cent Alcohol												
61		0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10
62		.10	.11	.12	.12	.13	.14	.14	.16	.16	.17	.18	.20
63		.16	.17	.18	.19	.20	.20	.21	.23	.24	.25	.27	.29
64		.22	.23	.24	.25	.26	.27	.29	.31	.32	.34	.37	.39
65		.28	.29	.30	.32	.33	.34	.36	.39	.41	.43	.46	.49
66		.34	.35	.36	.38	.40	.42	.44	.47	.50	.52	.56	.59
67		.41	.42	.43	.45	.47	.50	.52	.55	.58	.61	.65	.70
68		.48	.48	.50	.52	.54	.57	.60	.64	.67	.71	.75	.80
69		.55	.56	.57	.59	.62	.66	.68	.73	.76	.80	.85	.91
70		.62	.63	.64	.67	.70	.74	.77	.81	.86	.90	.96	1.02
72		.77	.78	.80	.83	.86	.90	.94	.99	1.04	1.10	1.16	1.23
74		.93	.94	.96	1.00	1.03	1.09	1.13	1.18	1.25	1.32	1.39	1.46
76			1.10	1.13	1.17	1.21	1.27	1.32	1.38	1.46	1.54	1.61	1.70
78			1.28	1.31	1.35	1.40	1.46	1.52	1.59	1.67	1.76	1.84	1.94
80			1.46	1.50	1.54	1.60	1.66	1.73	1.80	1.89	1.99	2.09	2.20
82			1.64	1.69	1.74	1.80	1.87	1.94	2.02	2.12	2.22	2.34	2.45
84			1.84	1.89	1.94	2.00	2.08	2.16	2.25	2.35	2.47	2.59	2.71
86				2.09	2.15	2.22	2.30	2.39	2.49	2.60	2.72	2.84	2.97
88				2.30	2.37	2.44	2.53	2.62	2.73	2.85	2.98	3.10	3.23
90				2.52	2.59	2.66	2.76	2.86	2.98	3.11	3.24	3.36	3.50
92				2.74	2.82	2.89	3.00	3.11	3.24	3.37	3.51	3.64	3.78
94				2.97	3.04	3.12	3.24	3.36	3.50	3.63	3.78	3.92	4.07
96					3.28	3.36	3.49	3.62	3.76	3.90	4.05	4.20	4.36
98					3.52	3.60	3.74	3.88	4.03	4.17	4.32	4.50	4.66
100					3.76	3.85	4.00	4.15	4.30	4.45	4.60	4.78	4.95

TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume											
	13	14	15	16	17	18	19	20	21	22	23	24
	Add to Observed Per Cent Alcohol											
50	0.90	0.99	1.09	1.19	1.30	1.41	1.52	1.62	1.72	1.82	1.90	1.98
51	.82	.90	.99	1.08	1.18	1.28	1.38	1.47	1.56	1.64	1.71	1.79
52	.74	.80	.89	.96	1.06	1.14	1.23	1.31	1.38	1.46	1.52	1.58
53	.65	.71	.78	.85	.94	1.00	1.08	1.15	1.21	1.28	1.34	1.39
54	.57	.62	.68	.74	.81	.86	.94	.99	1.04	1.10	1.15	1.20
55	.48	.52	.57	.62	.68	.72	.78	.83	.87	.92	.96	1.00
56	.38	.42	.46	.49	.54	.58	.63	.67	.69	.74	.77	.80
57	.29	.32	.35	.37	.40	.44	.47	.51	.53	.56	.58	.60
58	.19	.21	.23	.24	.26	.29	.32	.34	.35	.38	.40	.40
59	.10	.11	.12	.12	.13	.14	.16	.17	.18	.19	.20	.20
	Subtract from Observed Per Cent Alcohol											
	13	14	15	16	17	18	19	20	21	22	23	24
61	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.18	0.18	0.18
62	.21	.22	.24	.26	.27	.29	.30	.32	.34	.36	.37	.38
63	.31	.32	.35	.38	.41	.44	.46	.49	.51	.53	.55	.56
64	.42	.44	.48	.52	.54	.58	.62	.66	.68	.71	.74	.77
65	.52	.55	.60	.65	.68	.73	.78	.82	.85	.90	.92	.96
66	.63	.66	.71	.77	.82	.88	.94	.98	1.02	1.07	1.11	1.16
67	.74	.78	.84	.90	.96	1.03	1.10	1.15	1.20	1.25	1.30	1.35
68	.85	.91	.97	1.03	1.10	1.18	1.26	1.33	1.38	1.44	1.49	1.54
69	.97	1.02	1.10	1.17	1.25	1.33	1.42	1.48	1.54	1.61	1.66	1.72
70	1.08	1.14	1.23	1.31	1.40	1.49	1.58	1.65	1.72	1.78	1.84	1.91
72	1.31	1.39	1.50	1.60	1.70	1.80	1.90	2.00	2.06	2.13	2.20	2.27
74	1.55	1.65	1.76	1.88	1.99	2.10	2.22	2.32	2.41	2.48	2.56	2.65
76	1.80	1.91	2.03	2.16	2.28	2.41	2.54	2.65	2.76	2.84	2.93	3.03
78	2.05	2.17	2.30	2.44	2.58	2.72	2.86	2.98	3.10	3.20	3.30	3.40
80	2.31	2.44	2.58	2.72	2.87	3.02	3.17	3.33	3.45	3.56	3.67	3.78
82	2.57	2.71	2.86	3.00	3.16	3.33	3.50	3.66	3.79	3.92	4.04	4.18
84	2.84	2.98	3.13	3.29	3.46	3.63	3.81	4.00	4.14	4.28	4.42	4.56
86	3.11	3.26	3.41	3.58	3.76	3.94	4.13	4.33	4.49	4.65	4.80	4.94
88	3.38	3.54	3.70	3.88	4.07	4.26	4.46	4.67	4.84	5.00	5.17	5.32
90	3.66	3.83	4.00	4.18	4.38	4.58	4.78	5.01	5.19	5.36	5.53	5.69
92	3.94	4.11	4.29	4.48	4.69	4.90	5.12	5.35	5.54	5.72	5.90	6.07
94	4.23	4.40	4.58	4.79	5.00	5.22	5.46	5.69	5.89	6.08	6.28	6.45
96	4.53	4.69	4.87	5.10	5.32	5.55	5.80	6.03	6.24	6.44	6.64	6.82
98	4.83	5.00	5.18	5.41	5.64	5.88	6.13	6.38	6.60	6.80	7.02	7.20
100	5.13	5.30	5.49	5.72	5.95	6.21	6.46	6.72	6.95	7.17	7.40	7.59

TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	25	26	27	28	29	30	31	32	33	34	35
Add to Observed Per Cent Alcohol											
50	2.06	2.12	2.18	2.24	2.28	2.31	2.32	2.32	2.32	2.31	2.29
51	1.85	1.90	1.96	2.02	2.05	2.08	2.10	2.09	2.09	2.08	2.07
52	1.64	1.69	1.74	1.78	1.82	1.84	1.85	1.86	1.86	1.85	1.84
53	1.44	1.48	1.52	1.56	1.58	1.60	1.61	1.62	1.63	1.62	1.61
54	1.24	1.27	1.30	1.34	1.36	1.36	1.38	1.39	1.40	1.38	1.38
55	1.03	1.06	1.08	1.10	1.12	1.13	1.14	1.15	1.16	1.15	1.15
56	.82	.85	.87	.89	.90	.90	.91	.92	.92	.92	.92
57	.62	.64	.65	.66	.67	.67	.68	.69	.70	.69	.69
58	.41	.42	.43	.44	.44	.44	.45	.46	.46	.46	.46
59	.21	.21	.21	.22	.22	.22	.22	.22	.23	.23	.23
Subtract from Observed Per Cent Alcohol											
61	0.19	0.20	0.20	0.21	0.22	0.23	0.23	0.23	0.23	0.23	0.23
62	.39	.40	.41	.42	.44	.46	.46	.46	.46	.46	.46
63	.59	.60	.62	.64	.66	.68	.68	.68	.68	.68	.68
64	.79	.80	.83	.86	.88	.91	.91	.91	.91	.91	.91
65	.99	1.00	1.04	1.08	1.10	1.12	1.13	1.13	1.14	1.14	1.14
66	1.19	1.21	1.25	1.30	1.32	1.35	1.36	1.36	1.36	1.36	1.36
67	1.39	1.41	1.45	1.50	1.54	1.57	1.58	1.59	1.60	1.60	1.60
68	1.58	1.64	1.68	1.72	1.76	1.79	1.80	1.81	1.82	1.82	1.82
69	1.77	1.82	1.86	1.91	1.96	2.00	2.02	2.03	2.04	2.04	2.04
70	1.97	2.02	2.08	2.12	2.18	2.22	2.24	2.26	2.27	2.27	2.27
72	2.36	2.42	2.48	2.54	2.60	2.66	2.68	2.70	2.71	2.72	2.72
74	2.74	2.81	2.88	2.96	3.04	3.10	3.12	3.15	3.16	3.18	3.18
76	3.14	3.21	3.30	3.38	3.46	3.52	3.56	3.58	3.60	3.63	3.64
78	3.51	3.61	3.70	3.78	3.86	3.95	3.99	4.03	4.06	4.08	4.09
80	3.90	4.00	4.10	4.19	4.28	4.37	4.42	4.48	4.51	4.53	4.54
82	4.29	4.40	4.50	4.60	4.70	4.80	4.86	4.91	4.95	4.98	5.00
84	4.68	4.80	4.91	5.02	5.12	5.24	5.30	5.35	5.40	5.42	5.44
86	5.07	5.20	5.32	5.44	5.54	5.64	5.72	5.79	5.84	5.88	5.90
88	5.46	5.60	5.72	5.84	5.95	6.06	6.14	6.20	6.26	6.31	6.34
90	5.84	5.98	6.12	6.24	6.36	6.46	6.55	6.62	6.68	6.74	6.78
92	6.23	6.38	6.52	6.66	6.77	6.87	6.97	7.04	7.12	7.18	7.22
94	6.62	6.78	6.93	7.06	7.18	7.29	7.38	7.47	7.54	7.61	7.66
96	7.00	7.17	7.32	7.46	7.60	7.71	7.82	7.90	7.98	8.06	8.10
98	7.40	7.57	7.72	7.87	8.01	8.12	8.24	8.33	8.42	8.50	8.54
100	7.78	7.96	8.12	8.28	8.42	8.55	8.68	8.76	8.84	8.93	9.00

TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Tempera- ture in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	36	37	38	39	40	45	50	55	60	65	70
	Add to Observed Per Cent Alcohol										
50	2.28	2.27	2.26	2.25	2.24	2.14	2.04	1.98	1.90	1.85	1.78
51	2.06	2.04	2.03	2.03	2.02	1.91	1.84	1.78	1.71	1.66	1.60
52	1.82	1.80	1.80	1.80	1.79	1.71	1.64	1.58	1.52	1.47	1.42
53	1.60	1.58	1.58	1.58	1.56	1.50	1.44	1.38	1.33	1.29	1.25
54	1.37	1.36	1.36	1.36	1.34	1.28	1.23	1.19	1.14	1.11	1.08
55	1.14	1.13	1.13	1.13	1.11	1.06	1.02	.99	.95	.92	.90
56	.91	.90	.90	.90	.89	.85	.81	.79	.76	.74	.72
57	.68	.67	.68	.68	.67	.64	.61	.59	.57	.55	.54
58	.46	.46	.46	.46	.45	.42	.40	.39	.39	.38	.36
59	.23	.23	.23	.23	.23	.21	.20	.20	.19	.18	.18
	Subtract from Observed Per Cent Alcohol										
61	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.20	0.20	0.18	0.18
62	.46	.46	.46	.45	.45	.44	.42	.40	.39	.38	.36
63	.68	.68	.68	.68	.68	.66	.62	.60	.58	.56	.54
64	.92	.92	.91	.90	.90	.87	.84	.81	.78	.75	.72
65	1.14	1.14	1.13	1.12	1.12	1.09	1.05	1.01	.97	.94	.90
66	1.37	1.36	1.36	1.35	1.34	1.30	1.25	1.21	1.17	1.13	1.09
67	1.60	1.60	1.60	1.58	1.56	1.52	1.46	1.41	1.37	1.32	1.27
68	1.82	1.82	1.81	1.80	1.79	1.74	1.66	1.61	1.55	1.50	1.45
69	2.04	2.03	2.03	2.03	2.01	1.96	1.88	1.81	1.75	1.69	1.63
70	2.27	2.27	2.26	2.25	2.24	2.17	2.09	2.02	1.95	1.88	1.82
72	2.72	2.72	2.72	2.70	2.68	2.61	2.51	2.42	2.34	2.26	2.18
74	3.18	3.17	3.17	3.16	3.14	3.04	2.93	2.83	2.73	2.65	2.56
76	3.63	3.62	3.62	3.60	3.58	3.47	3.35	3.24	3.13	3.03	2.93
78	4.09	4.08	4.07	4.06	4.02	3.92	3.78	3.64	3.53	3.42	3.30
80	4.54	4.53	4.52	4.50	4.48	4.36	4.20	4.05	3.93	3.80	3.68
82	5.00	4.98	4.98	4.96	4.94	4.81	4.63	4.47	4.33	4.19	4.06
84	5.45	5.44	5.43	5.40	5.38	5.25	5.06	4.88	4.73	4.58	4.44
86	5.90	5.89	5.88	5.86	5.84	5.70	5.49	5.30	5.14	4.98	4.82
88	6.35	6.34	6.33	6.31	6.29	6.14	5.92	5.72	5.54	5.37	5.20
90	6.80	6.80	6.78	6.76	6.73	6.58	6.36	6.14	5.95	5.76	5.59
92	7.25	7.25	7.22	7.20	7.18	7.03	6.80	6.56	6.36	6.16	5.98
94	7.70	7.70	7.67	7.66	7.63	7.48	7.24	6.98	6.77	6.56	6.37
96	8.14	8.15	8.12	8.11	8.08	7.92	7.68	7.40	7.19	6.96	6.76
98	8.58	8.60	8.58	8.56	8.54	8.36	8.11	7.82	7.60	7.36	7.15
100	9.03	9.04	9.03	9.01	8.98	8.81	8.45	8.25	8.02	7.76	7.54

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TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	75	80	81	82	83	84	85	86	87	88	89
Add to Observed Per Cent Alcohol											
50	1.71	1.63	1.62	1.60	1.58	1.56	1.53	1.51	1.48	1.46	1.43
51	1.54	1.47	1.46	1.44	1.42	1.40	1.38	1.36	1.33	1.31	1.28
52	1.36	1.30	1.30	1.28	1.26	1.24	1.22	1.20	1.18	1.16	1.14
53	1.20	1.15	1.14	1.12	1.11	1.09	1.07	1.06	1.04	1.02	1.00
54	1.04	.98	.98	.96	.95	.94	.92	.91	.89	.88	.86
55	.87	.82	.81	.80	.79	.78	.76	.75	.74	.74	.72
56	.70	.66	.65	.64	.63	.62	.61	.60	.59	.58	.57
57	.53	.49	.49	.48	.48	.47	.46	.46	.45	.44	.43
58	.34	.32	.32	.32	.31	.30	.30	.30	.30	.29	.28
59	.17	.16	.16	.16	.16	.15	.15	.15	.15	.15	.14
Subtract from Observed Per Cent Alcohol											
61	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15
62	.34	.34	.34	.32	.32	.32	.32	.31	.31	.31	.30
63	.52	.50	.50	.48	.48	.48	.48	.47	.46	.46	.44
64	.70	.68	.66	.65	.65	.64	.63	.62	.61	.60	.59
65	.86	.84	.82	.82	.81	.80	.79	.78	.77	.76	.74
66	1.05	1.00	.99	.98	.97	.96	.94	.93	.92	.90	.88
67	1.22	1.17	1.16	1.14	1.13	1.12	1.10	1.09	1.08	1.06	1.02
68	1.40	1.33	1.32	1.31	1.29	1.28	1.26	1.24	1.22	1.20	1.17
69	1.57	1.50	1.49	1.47	1.46	1.44	1.42	1.40	1.38	1.36	1.32
70	1.75	1.68	1.66	1.64	1.62	1.60	1.58	1.56	1.54	1.51	1.48
72	2.10	2.02	2.00	1.97	1.95	1.93	1.90	1.88	1.85	1.82	1.78
74	2.46	2.36	2.34	2.30	2.28	2.26	2.24	2.20	2.17	2.13	2.09
76	2.81	2.70	2.68	2.64	2.61	2.59	2.56	2.52	2.48	2.44	2.40
78	3.18	3.04	3.02	2.98	2.94	2.92	2.88	2.84	2.80	2.76	2.71
80	3.54	3.38	3.36	3.32	3.28	3.26	3.22	3.17	3.13	3.08	3.02
82	3.90	3.72	3.71	3.66	3.62	3.59	3.54	3.50	3.45	3.40	3.33
84	4.27	4.08	4.05	4.00	3.96	3.92	3.88	3.83	3.77	3.72	3.65
86	4.64	4.43	4.39	4.35	4.30	4.26	4.21	4.16	4.10	4.04	3.96
88	5.00	4.78	4.75	4.70	4.65	4.60	4.55	4.50	4.44	4.37	4.29
90	5.37	5.14	5.10	5.06	5.00	4.95	4.88	4.83	4.77	4.70	4.61
92	5.75	5.50	5.46	5.42	5.36	5.30	5.23	5.18	5.10	5.03	4.94
94	6.12	5.86	5.81	5.76	5.70	5.64	5.58	5.51	5.44	5.36	5.26
96	6.50	6.23	6.17	6.12	6.06	5.99	5.92	5.86	5.78	5.69	5.59
98	6.88	6.60	6.50	6.48	6.41	6.34	6.26	6.20	6.11	6.02	5.92
100	7.26	6.96	6.89	6.84	6.76	6.70	6.61	6.54	6.44	6.36	6.26

TABLE 4.—Temperature Corrections to Readings of Alcoholometers (Standard at 60° F)—Continued

Observed Temperature in Degrees Fahrenheit	Observed Per Cent Alcohol by Volume										
	90	91	92	93	94	95	96	97	98	99	100
Add to Observed Per Cent Alcohol											
50	1.39	1.36	1.32	1.27	1.22	1.17	1.12	1.06	0.99	0.93	.....
51	1.25	1.22	1.18	1.14	1.10	1.06	1.01	.95	.89	.84	.....
52	1.12	1.09	1.06	1.02	.98	.94	.90	.85	.79	.74	.....
53	.98	.96	.93	.90	.86	.83	.79	.74	.70	.65	.....
54	.84	.82	.80	.77	.74	.72	.68	.64	.60	.56	.....
55	.70	.69	.66	.64	.62	.60	.57	.53	.50	.47	.....
56	.56	.55	.53	.52	.49	.48	.45	.43	.40	.38	.....
57	.42	.41	.40	.39	.37	.36	.34	.32	.30	.29	.....
58	.28	.27	.26	.26	.24	.24	.23	.21	.20	.19	.....
59	.14	.14	.13	.13	.12	.12	.12	.11	.10	.10	.....
Subtract from Observed Per Cent Alcohol											
61	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.10	0.09
62	.29	.28	.27	.26	.25	.24	.23	.22	.21	.19	.18
63	.43	.42	.41	.39	.38	.36	.35	.33	.31	.29	.27
64	.58	.55	.54	.52	.51	.49	.46	.44	.41	.39	.36
65	.72	.70	.68	.66	.64	.61	.58	.55	.52	.49	.46
66	.86	.84	.82	.79	.76	.73	.70	.67	.63	.59	.55
67	1.00	.98	.96	.93	.90	.86	.82	.78	.74	.70	.64
68	1.15	1.12	1.09	1.06	1.02	.98	.94	.90	.85	.80	.74
69	1.30	1.26	1.23	1.20	1.16	1.10	1.06	1.02	.96	.90	.84
70	1.45	1.41	1.37	1.34	1.29	1.23	1.19	1.14	1.07	1.00	.94
72	1.74	1.70	1.65	1.61	1.55	1.49	1.43	1.37	1.30	1.22	1.13
74	2.05	2.00	1.94	1.89	1.82	1.75	1.69	1.61	1.53	1.43	1.33
76	2.35	2.29	2.23	2.17	2.09	2.01	1.94	1.85	1.76	1.65	1.53
78	2.65	2.59	2.52	2.46	2.36	2.28	2.20	2.10	2.00	1.87	1.73
80	2.96	2.89	2.82	2.74	2.64	2.56	2.46	2.35	2.24	2.09	1.93
82	3.26	3.20	3.12	3.03	2.92	2.84	2.72	2.60	2.48	2.32	2.14
84	3.57	3.50	3.39	3.32	3.21	3.10	2.96	2.86	2.73	2.56	2.36
86	3.89	3.80	3.72	3.62	3.51	3.38	3.26	3.13	2.98	2.80	2.58
88	4.20	4.12	4.02	3.91	3.80	3.66	3.54	3.39	3.24	3.06	2.81
90	4.52	4.42	4.32	4.20	4.08	3.94	3.81	3.66	3.50	3.30	3.03
92	4.84	4.74	4.62	4.50	4.38	4.23	4.10	3.93	3.76	3.55	3.26
94	5.16	5.06	4.94	4.80	4.67	4.52	4.38	4.20	4.02	3.80	3.50
96	5.49	5.39	5.25	5.11	4.97	4.82	4.67	4.48	4.29	4.06	3.73
98	5.82	5.70	5.56	5.42	5.27	5.12	4.95	4.76	4.55	4.31	3.96
100	6.15	6.02	5.88	5.74	5.58	5.42	5.24	5.04	4.82	4.56	4.21

TABLE 5.—Percentages by Volume at 60° F, Corresponding to Various Percentages by Weight in Mixtures of Ethyl Alcohol and Water

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.000	0.126	0.252	0.378	0.504	0.630	0.755	0.881	1.007	1.132
1	1.257	1.382	1.508	1.633	1.759	1.884	2.009	2.134	2.260	2.385
2	2.510	2.635	2.760	2.885	3.010	3.135	3.259	3.384	3.509	3.633
3	3.758	3.883	4.007	4.132	4.256	4.381	4.505	4.629	4.754	4.878
4	5.002	5.126	5.250	5.374	5.499	5.623	5.747	5.871	5.995	6.119
5	6.243	6.367	6.491	6.614	6.738	6.862	6.985	7.109	7.232	7.356
6	7.479	7.602	7.726	7.849	7.972	8.096	8.219	8.342	8.466	8.589
7	8.712	8.835	8.958	9.081	9.205	9.328	9.451	9.574	9.697	9.820
8	9.943	10.066	10.189	10.311	10.434	10.557	10.679	10.802	10.925	11.047
9	11.169	11.292	11.414	11.536	11.659	11.781	11.904	12.026	12.149	12.271
10	12.393	12.515	12.637	12.760	12.882	13.004	13.126	13.248	13.370	13.492
11	13.613	13.735	13.857	13.979	14.101	14.223	14.345	14.466	14.588	14.710
12	14.832	14.954	15.075	15.197	15.319	15.440	15.562	15.683	15.805	15.926
13	16.047	16.168	16.290	16.411	16.532	16.654	16.775	16.896	17.017	17.138
14	17.259	17.380	17.501	17.622	17.743	17.864	17.985	18.106	18.227	18.348
15	18.469	18.590	18.711	18.832	18.952	19.073	19.194	19.315	19.435	19.556
16	19.776	19.797	20.038	20.158	20.279	20.399	20.519	20.640	20.760	20.880
17	20.880	21.000	21.120	21.241	21.361	21.481	21.601	21.721	21.841	21.961
18	22.081	22.201	22.321	22.441	22.561	22.680	22.800	22.919	23.039	23.159
19	23.278	23.398	23.517	23.636	23.756	23.876	23.995	24.114	24.234	24.353
20	24.472	24.591	24.710	24.829	24.949	25.068	25.187	25.305	25.424	25.543
21	25.662	25.781	25.900	26.018	26.137	26.256	26.375	26.493	26.612	26.730
22	26.849	26.968	27.086	27.204	27.323	27.441	27.559	27.677	27.796	27.914
23	28.032	28.150	28.268	28.386	28.504	28.622	28.740	28.858	28.976	29.093
24	29.210	29.328	29.446	29.563	29.681	29.799	29.917	30.035	30.152	30.270
25	30.388	30.505	30.622	30.739	30.855	30.972	31.089	31.205	31.322	31.438
26	31.555	31.672	31.788	31.905	32.021	32.138	32.254	32.370	32.487	32.603
27	32.719	32.835	32.951	33.068	33.184	33.300	33.416	33.532	33.647	33.763
28	33.879	33.995	34.111	34.227	34.342	34.458	34.573	34.688	34.803	34.918
29	35.033	35.148	35.263	35.378	35.493	35.608	35.723	35.838	35.952	36.066
30	36.181	36.296	36.410	36.524	36.639	36.753	36.867	36.981	37.095	37.209
31	37.323	37.437	37.551	37.664	37.778	37.892	38.005	38.119	38.232	38.346
32	38.459	38.572	38.686	38.799	38.912	39.025	39.138	39.251	39.364	39.477
33	39.590	39.703	39.816	39.928	40.041	40.154	40.266	40.379	40.492	40.604
34	40.716	40.828	40.940	41.052	41.163	41.275	41.386	41.498	41.609	41.721
35	41.832	41.943	42.055	42.166	42.277	42.389	42.500	42.611	42.722	42.833
36	42.944	43.055	43.165	43.276	43.387	43.498	43.608	43.719	43.829	43.939
37	44.050	44.160	44.270	44.381	44.490	44.600	44.710	44.820	44.930	45.039
38	45.149	45.259	45.368	45.478	45.587	45.696	45.806	45.915	46.024	46.133
39	46.242	46.351	46.460	46.569	46.678	46.786	46.895	47.003	47.112	47.220
40	47.328	47.436	47.544	47.652	47.760	47.868	47.976	48.084	48.192	48.299
41	48.407	48.515	48.622	48.730	48.837	48.945	49.052	49.159	49.266	49.373
42	49.480	49.587	49.694	49.801	49.907	50.014	50.120	50.226	50.333	50.439
43	50.545	50.651	50.757	50.864	50.970	51.076	51.182	51.288	51.394	51.499
44	51.605	51.711	51.816	51.922	52.027	52.132	52.238	52.343	52.448	52.553
45	52.658	52.763	52.868	52.973	53.078	53.182	53.287	53.392	53.496	53.601
46	53.705	53.809	53.914	54.018	54.122	54.226	54.330	54.434	54.538	54.642
47	54.746	54.850	54.954	55.057	55.161	55.264	55.368	55.471	55.574	55.677
48	55.780	55.883	55.986	56.089	56.192	56.295	56.398	56.500	56.603	56.706
49	56.808	56.910	57.013	57.116	57.218	57.320	57.422	57.522	57.626	57.728
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743

TABLE 5.—Percentages by Volume at 60° F, Corresponding to Various Percentages by Weight in Mixtures of Ethyl Alcohol and Water—Continued

Per Cent Alcohol by Weight	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743
51	58.844	58.945	59.046	59.147	59.248	59.349	59.450	59.551	59.651	59.752
52	59.852	59.952	60.053	60.154	60.254	60.354	60.454	60.554	60.654	60.754
53	60.854	60.954	61.054	61.154	61.254	61.353	61.453	61.552	61.652	61.751
54	61.850	61.949	62.048	62.147	62.246	62.344	62.443	62.542	62.640	62.738
55	62.837	62.936	63.034	63.132	63.231	63.329	63.427	63.526	63.624	63.722
56	63.820	63.918	64.016	64.114	64.212	64.310	64.408	64.505	64.603	64.701
57	64.798	64.895	64.993	65.090	65.188	65.285	65.382	65.479	65.575	65.672
58	65.768	65.865	65.961	66.058	66.154	66.251	66.347	66.444	66.540	66.636
59	66.732	66.828	66.924	67.020	67.116	67.212	67.308	67.404	67.499	67.595
60	67.690	67.785	67.881	67.976	68.071	68.166	68.261	68.356	68.451	68.546
61	68.641	68.736	68.831	68.925	69.020	69.115	69.209	69.304	69.398	69.492
62	69.586	69.680	69.774	69.868	69.962	70.056	70.149	70.243	70.336	70.430
63	70.523	70.616	70.710	70.803	70.897	70.990	71.083	71.176	71.269	71.362
64	71.455	71.548	71.641	71.733	71.826	71.918	72.011	72.103	72.196	72.288
65	72.380	72.472	72.564	72.656	72.748	72.840	72.932	73.024	73.116	73.207
66	73.299	73.391	73.482	73.574	73.665	73.756	73.847	73.938	74.029	74.120
67	74.211	74.302	74.393	74.484	74.575	74.665	74.756	74.846	74.937	75.027
68	75.117	75.207	75.297	75.387	75.477	75.567	75.657	75.747	75.837	75.926
69	76.016	76.106	76.195	76.285	76.374	76.464	76.553	76.642	76.731	76.820
70	76.909	76.998	77.087	77.176	77.264	77.353	77.441	77.529	77.618	77.706
71	77.794	77.882	77.970	78.058	78.146	78.234	78.322	78.410	78.497	78.584
72	78.672	78.760	78.847	78.934	79.022	79.109	79.196	79.283	79.370	79.457
73	79.544	79.631	79.718	79.805	79.892	79.978	80.065	80.151	80.238	80.324
74	80.410	80.496	80.582	80.668	80.754	80.840	80.926	81.012	81.098	81.183
75	81.269	81.355	81.440	81.526	81.611	81.696	81.781	81.866	81.951	82.036
76	82.121	82.206	82.291	82.376	82.461	82.545	82.630	82.714	82.799	82.883
77	82.967	83.051	83.135	83.219	83.303	83.387	83.471	83.555	83.638	83.722
78	83.805	83.888	83.972	84.055	84.138	84.221	84.304	84.387	84.470	84.553
79	84.636	84.719	84.801	84.884	84.966	85.049	85.131	85.213	85.295	85.377
80	85.459	85.541	85.623	85.705	85.787	85.868	85.950	86.031	86.113	86.194
81	86.275	86.356	86.437	86.518	86.599	86.680	86.761	86.842	86.922	87.002
82	87.083	87.164	87.244	87.324	87.405	87.485	87.565	87.645	87.725	87.805
83	87.885	87.965	88.045	88.124	88.204	88.283	88.362	88.441	88.520	88.599
84	88.678	88.757	88.836	88.915	88.994	89.072	89.151	89.229	89.308	89.386
85	89.464	89.542	89.620	89.698	89.776	89.854	89.932	90.009	90.086	90.163
86	90.240	90.317	90.394	90.471	90.548	90.625	90.702	90.779	90.855	90.932
87	91.008	91.084	91.161	91.237	91.313	91.388	91.464	91.540	91.615	91.691
88	91.766	91.841	91.917	91.992	92.068	92.143	92.218	92.293	92.367	92.442
89	92.517	92.591	92.666	92.740	92.814	92.888	92.962	93.035	93.108	93.181
90	93.254	93.327	93.400	93.473	93.546	93.619	93.692	93.764	93.837	93.910
91	93.982	94.054	94.126	94.198	94.270	94.342	94.414	94.486	94.557	94.629
92	94.700	94.771	94.842	94.913	94.984	95.055	95.126	95.196	95.267	95.337
93	95.407	95.477	95.547	95.617	95.687	95.757	95.826	95.896	95.965	96.034
94	96.103	96.172	96.241	96.310	96.378	96.447	96.515	96.583	96.652	96.720
95	96.787	96.855	96.922	96.990	97.057	97.125	97.192	97.259	97.326	97.392
96	97.459	97.526	97.592	97.658	97.724	97.790	97.856	97.921	97.987	98.052
97	98.117	98.182	98.247	98.312	98.376	98.440	98.505	98.569	98.633	98.696
98	98.759	98.822	98.886	98.949	99.012	99.075	99.137	99.200	99.262	99.324
99	99.386	99.448	99.510	99.572	99.633	99.695	99.756	99.817	99.878	99.939
100	100.000									

TABLE 6.—Percentages by Weight, Corresponding to Various Percentages by Volume at 60° F in Mixtures of Ethyl Alcohol and Water

Per Cent Alcohol by Volume at 60° F	Per Cent Alcohol by Weight	Differences	Per Cent Alcohol by Volume at 60° F	Per Cent Alcohol by Weight	Differences
0	0.000		50	42.487	
1	0.795	0.795	51	43.428	0.941
2	1.593	.798	52	44.374	.946
3	2.392	.799	53	45.326	.952
4	3.194	.802	54	46.283	.957
		.804			.962
5	3.998		55	47.245	
6	4.804	.806	56	48.214	.969
7	5.612	.808	57	49.187	.973
8	6.422	.810	58	50.167	.980
9	7.234	.812	59	51.154	.987
		.813			.993
10	8.047		60	52.147	
11	8.862	.815	61	53.146	.999
12	9.679	.817	62	54.152	1.006
13	10.497	.818	63	55.165	1.013
14	11.317	.820	64	56.184	1.019
		.821			1.024
15	12.138		65	57.208	
16	12.961	.823	66	58.241	1.033
17	13.786	.825	67	59.279	1.038
18	14.612	.826	68	60.325	1.046
19	15.440	.828	69	61.379	1.054
		.829			1.062
20	16.269		70	62.441	
21	17.100	.831	71	63.511	1.070
22	17.933	.833	72	64.588	1.077
23	18.768	.835	73	65.674	1.086
24	19.604	.836	74	66.768	1.094
		.839			1.102
25	20.443		75	67.870	
26	21.285	.842	76	68.982	1.112
27	22.127	.842	77	70.102	1.120
28	22.973	.846	78	71.234	1.132
29	23.820	.847	79	72.375	1.141
		.850			1.151
30	24.670		80	73.526	
31	25.524	.854	81	74.686	1.160
32	26.382	.858	82	75.858	1.172
33	27.242	.860	83	77.039	1.181
34	28.104	.862	84	78.233	1.194
		.867			1.208
35	28.971		85	79.441	
36	29.842	.871	86	80.662	1.221
37	30.717	.875	87	81.897	1.235
38	31.596	.879	88	83.144	1.247
39	32.478	.882	89	84.408	1.264
		.886			1.281
40	33.364		90	85.689	
41	34.254	.890	91	86.989	1.300
42	35.150	.896	92	88.310	1.321
43	36.050	.900	93	89.652	1.342
44	36.955	.905	94	91.025	1.373
		.910			1.398
45	37.865		95	92.423	
46	38.778	.913	96	93.851	1.428
47	39.697	.919	97	95.315	1.464
48	40.622	.925	98	96.820	1.505
49	41.551	.929	99	98.381	1.561
		.936			1.619
50	42.487		100	100.000	

TABLE 7.—Temperature Corrections to Readings of Alcoholometers (Standard at 20° C)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which Tables 1, 2, 3, 4, 5, and 6 are calculated. The hydrometer is assumed to be of Jena 16711 glass.]

Observed Tempera- ture in Degrees Centigrade	Observed Per Cent Alcohol by Weight																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Add to Observed Per Cent Alcohol																					
10	0.67	0.91	1.47	2.43	3.18	3.55	3.59	3.55	3.49	3.47	3.45	3.45	3.45	3.45	3.43	3.42	3.36	3.26	3.08	2.86	
11																					
12																					
13																					
14																					
15																					
16																					
17																					
18																					
19																					
Subtract from Observed Per Cent Alcohol																					
21	0.13	0.17	0.24	0.29	0.33	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.33	0.32	0.30	0.27
22																					
23																					
24																					
25																					
26																					
27																					
28																					
29																					
30																					
31	1.61	2.05	2.69	3.28	3.70	3.86	3.89	3.86	3.82	3.86	3.86	3.86	3.86	3.86	3.84	3.84	3.82	3.75	3.61	3.40	3.07
32																					
33																					
34																					
35																					
36																					
37																					
38																					
39																					
40																					

TABLE 8.—Density at 15° C of Mixtures (by weight) of Methyl Alcohol and Water

[Calculated from the specific gravity determinations of Doroshovskii and Rozhdestvenskii at $\frac{15^\circ}{15^\circ}\text{C}^\circ$]

Per Cent Methyl Alcohol by Weight	D $_{4}^{15^\circ}\text{C}$	Differences	Per Cent Methyl Alcohol by Weight	D $_{4}^{15^\circ}\text{C}$	Differences
0	.99913		50	.91852	
1	.99727	0.00186	51	.91653	0.00199
2	.99543	184	52	.91451	202
3	.99370	173	53	.91248	203
4	.99198	169	54	.91044	204
5	.99029		55	.90839	205
6	.98864	165	56	.90631	208
7	.98701	163	57	.90421	210
8	.98547	154	58	.90210	211
9	.98394	153	59	.89996	214
10	.98241		60	.89781	215
11	.98093	148	61	.89563	218
12	.97945	148	62	.89341	222
13	.97802	143	63	.89117	224
14	.97660	142	64	.88890	227
15	.97518	142	65	.88662	228
16	.97377	141	66	.88433	229
17	.97237	140	67	.88203	230
18	.97096	141	68	.87971	232
19	.96955	141	69	.87739	232
20	.96814		70	.87507	236
21	.96673	141	71	.87271	238
22	.96533	140	72	.87033	241
23	.96392	141	73	.86792	246
24	.96251	143	74	.86546	246
25	.96108		75	.86300	
26	.95963	145	76	.86051	249
27	.95817	146	77	.85801	250
28	.95668	149	78	.85551	250
29	.95518	150	79	.85300	251
30	.95366	152	80	.85048	252
31	.95213	153	81	.84794	254
32	.95056	157	82	.84536	258
33	.94896	160	83	.84274	262
34	.94734	162	84	.84009	265
35	.94570	164	85	.83742	267
36	.94404		86	.83475	267
37	.94237	166	87	.83207	268
38	.94067	167	88	.82937	270
39	.93894	170	89	.82667	270
40	.93720	173	90	.82396	271
41	.93543	174	91	.82124	272
42	.93365	177	92	.81849	275
43	.93185	180	93	.81568	281
44	.93001	184	94	.81285	283
45	.92815	186	95	.80999	286
46	.92627		96	.80713	286
47	.92436	188	97	.80428	285
48	.92242	191	98	.80143	285
49	.92048	194	99	.79859	284
50	.91852	196	100	.79577	282

* J. Russ., Phys. Chem. Soc., 41, pp. 977-996; 1909.

TABLE 9.—Specific Gravity at $\frac{15^{\circ}}{15^{\circ}}$ C of Mixtures (by Volume) of Methyl Alcohol and Water

[Calculated from the same data as Table 8]

Per Cent Methyl Alcohol by Volume at 15 C	D 15° 15° C	Differences	Per Cent Methyl Alcohol by Volume at 15 C	D 15° 15° C	Differences
0	1.00000		50	0.93326	0.00171
1	.99851	0.00149	51	.93155	173
2	.99703	148	52	.92982	176
3	.99560	143	53	.92806	180
4	.99422	139	54	.92626	183
5	.99283		55	.92443	187
6	.99146	137	56	.92256	189
7	.99011	135	57	.92067	190
8	.98877	134	58	.91877	195
9	.98746	131	59	.91682	199
		125			
10	.98621	125	60	.91483	201
11	.98496	126	61	.91282	203
12	.98370	123	62	.91079	206
13	.98247	122	63	.90873	210
14	.98125	122	64	.90663	213
15	.98003	119	65	.90450	216
16	.97884	118	66	.90234	220
17	.97766	118	67	.90014	224
18	.97648	118	68	.89790	229
19	.97530	117	69	.89561	234
20	.97413	118	70	.89327	239
21	.97295	118	71	.89088	244
22	.97177	119	72	.88844	248
23	.97058	119	73	.88596	250
24	.96939	119	74	.88346	254
25	.96820	120	75	.88092	256
26	.96700	120	76	.87836	258
27	.96580	121	77	.87578	266
28	.96459	121	78	.87312	272
29	.96338	122	79	.87040	280
30	.96216	125	80	.86760	286
31	.96091	125	81	.86474	294
32	.95966	128	82	.86180	297
33	.95838	130	83	.85883	301
34	.95708	132	84	.85582	306
35	.95576	133	85	.85276	309
36	.95443	135	86	.84967	321
37	.95308	138	87	.84646	332
38	.95170	141	88	.84314	343
39	.95029	143	89	.83971	348
40	.94886	145	90	.83623	354
41	.94741	148	91	.83269	362
42	.94593	150	92	.82907	369
43	.94443	152	93	.82538	375
44	.94291	155	94	.82163	391
45	.94136	157	95	.81772	409
46	.93979	159	96	.81363	421
47	.93820	163	97	.80942	428
48	.93657	164	98	.80514	432
49	.93493	167	99	.80082	435
50	.93326		100	.79647	

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TABLE 10.—Percentages by Volume at 15° C, Corresponding to Various Percentages by Weight in Mixtures of Methyl Alcohol and Water

Per Cent by Weight	Per Cent by Volume at 15° C	Differences	Per Cent by Weight	Per Cent by Volume at 15° C	Differences
0	0.000	1.253	50	57.712	1.027
1	1.253	1.249	51	58.739	1.020
2	2.502	1.244	52	59.759	1.014
3	3.746	1.240	53	60.773	1.008
4	4.986	1.236	54	61.781	1.002
5	6.222	1.232	55	62.783	.995
6	7.454	1.228	56	63.778	.989
7	8.682	1.225	57	64.767	.983
8	9.907	1.221	58	65.750	.975
9	11.128	1.217	59	66.725	.968
10	12.345	1.214	60	67.693	.961
11	13.559	1.211	61	68.654	.953
12	14.770	1.207	62	69.607	.945
13	15.977	1.204	63	70.552	.938
14	17.181	1.201	64	71.490	.930
15	18.382	1.197	65	72.420	.924
16	19.579	1.194	66	73.344	.918
17	20.773	1.190	67	74.262	.910
18	21.963	1.186	68	75.172	.905
19	23.149	1.183	69	76.077	.899
20	24.332	1.180	70	76.976	.888
21	25.512	1.176	71	77.864	.882
22	26.688	1.172	72	78.746	.872
23	27.860	1.169	73	79.618	.862
24	29.029	1.164	74	80.480	.856
25	30.193	1.161	75	81.336	.846
26	31.354	1.156	76	82.182	.840
27	32.510	1.152	77	83.022	.833
28	33.662	1.147	78	83.855	.825
29	34.809	1.143	79	84.680	.815
30	35.952	1.139	80	85.499	.811
31	37.091	1.133	81	86.310	.800
32	38.224	1.128	82	87.110	.789
33	39.352	1.124	83	87.899	.778
34	40.476	1.118	84	88.677	.771
35	41.594	1.114	85	89.448	.764
36	42.708	1.108	86	90.212	.756
37	43.816	1.103	87	90.968	.748
38	44.919	1.097	88	91.716	.740
39	46.016	1.093	89	92.456	.732
40	47.109	1.086	90	93.188	.724
41	48.195	1.082	91	93.912	.715
42	49.277	1.076	92	94.627	.699
43	50.353	1.069	93	95.326	.691
44	51.422	1.064	94	96.017	.680
45	52.486	1.058	95	96.697	.673
46	53.544	1.051	96	97.370	.666
47	54.595	1.044	97	98.036	.660
48	55.639	1.039	98	98.696	.653
49	56.678	1.034	99	99.351	.649
50	57.712		100	100.000	

TABLE 11.—Temperature Corrections to Readings of Saccharometers (Standard at 20° C)

[This table is calculated using the data on thermal expansion of sugar solutions by Plato¹, assuming the instrument to be of Jena 16^{mm} glass. The table should be used with caution and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Temperature in Degrees Centigrade	Observed Per Cent of Sugar													
	0	5	10	15	20	25	30	35	40	45	50	55	60	70
	Subtract from Observed Per cent													
0	0.30	0.49	0.65	0.77	0.89	0.99	1.08	1.16	1.24	1.31	1.37	1.41	1.44	1.49
5	.36	.47	.56	.65	.73	.80	.86	.91	.97	1.01	1.05	1.08	1.10	1.14
10	.32	.38	.43	.48	.52	.57	.60	.64	.67	.70	.72	.74	.75	.77
11	.31	.35	.40	.44	.48	.51	.55	.58	.60	.63	.65	.66	.68	.70
12	.29	.32	.36	.40	.43	.46	.50	.52	.54	.56	.58	.59	.60	.62
13	.26	.29	.32	.35	.38	.41	.44	.46	.48	.49	.51	.52	.53	.55
14	.24	.26	.29	.31	.34	.36	.38	.40	.41	.42	.44	.45	.46	.47
15	.20	.22	.24	.26	.28	.30	.32	.33	.34	.36	.36	.37	.38	.39
16	.17	.18	.20	.22	.23	.25	.26	.27	.28	.28	.29	.30	.31	.32
17	.13	.14	.15	.16	.18	.19	.20	.20	.21	.21	.22	.23	.23	.24
18	.09	.10	.10	.11	.12	.13	.13	.14	.14	.15	.15	.15	.15	.16
19	.05	.05	.05	.06	.06	.06	.07	.07	.07	.07	.08	.08	.08	.08
17.5	.11	.12	.12	.14	.15	.16	.16	.17	.17	.18	.18	.19	.19	.20
15.56 (60° F)	.18	.20	.22	.24	.26	.28	.29	.30	.30	.32	.33	.33	.34	.34
	Add to Observed Per Cent													
21	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09
22	.10	.10	.11	.12	.12	.13	.14	.14	.15	.15	.16	.16	.16	.16
23	.16	.16	.17	.17	.19	.20	.21	.21	.22	.23	.24	.24	.24	.24
24	.21	.22	.23	.24	.26	.27	.28	.29	.30	.31	.32	.32	.32	.32
25	.27	.28	.30	.31	.32	.34	.35	.36	.38	.38	.39	.39	.40	.39
26	.33	.34	.36	.37	.40	.40	.42	.44	.46	.47	.47	.48	.48	.48
27	.40	.41	.42	.44	.46	.48	.50	.52	.54	.54	.55	.56	.56	.56
28	.46	.47	.49	.51	.54	.56	.58	.60	.61	.62	.63	.64	.64	.64
29	.54	.55	.56	.59	.61	.63	.66	.68	.70	.70	.71	.72	.72	.72
30	.61	.62	.63	.66	.68	.71	.73	.76	.78	.78	.79	.80	.80	.81
35	.99	1.01	1.02	1.06	1.10	1.13	1.16	1.18	1.20	1.21	1.22	1.22	1.23	1.22
40	1.42	1.45	1.47	1.51	1.54	1.57	1.60	1.62	1.64	1.65	1.65	1.65	1.66	1.65
45	1.91	1.94	1.96	2.00	2.03	2.05	2.07	2.09	2.10	2.10	2.10	2.10	2.10	2.08
50	2.46	2.48	2.50	2.53	2.56	2.57	2.58	2.59	2.59	2.58	2.58	2.57	2.56	2.52
55	3.05	3.07	3.09	3.12	3.12	3.12	3.12	3.11	3.10	3.08	3.07	3.05	3.03	2.97
60	3.69	3.72	3.73	3.73	3.72	3.70	3.67	3.65	3.62	3.60	3.57	3.54	3.50	3.43
27.5	0.43	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.58	0.59	0.60	0.60	0.60

¹ Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 140; 1900.

TABLE 12.—Density^a of Solutions of Cane Sugar at 20° C

[This table is the basis for standardizing hydrometers indicating per cent of sugar at 20° C]

Per Cent Sugar	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051936	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055325	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095783	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106786	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114229	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166269	1.166775	1.167281	1.167786	1.168293	1.168800	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532

^a According to Dr. F. Plato (Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 153; 1900).

TABLE 12.—Density of Solutions of Cane Sugar at 20° C—Continued

Per Cent Sugar	Tenths of Per Cent									
	0	1	2	3	4	5	6	7	8	9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246234	1.246795	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273035	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295911	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300077	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306068	1.306669	1.307271	1.307872	1.308475	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312699	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335343	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342798	1.343421	1.344046	1.344671	1.345296	1.345922	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353456	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363590	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378326
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.402452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408398	1.409061	1.409723	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422390	1.423061	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460495	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275
90	1.479976	1.480677	1.481378	1.482080	1.482782	1.483484	1.484187	1.484890	1.485593	1.486297
91	1.487002	1.487707	1.488411	1.489117	1.489823	1.490528	1.491234	1.491941	1.492647	1.493355
92	1.494063	1.494771	1.495479	1.496188	1.496897	1.497606	1.498316	1.499026	1.499736	1.500447
93	1.501158	1.501870	1.502582	1.503293	1.504006	1.504719	1.505432	1.506146	1.506859	1.507574
94	1.508289	1.509004	1.509720	1.510435	1.511151	1.511868	1.512585	1.513302	1.514019	1.514737
95	1.515455	1.516174	1.516893	1.517612	1.518332	1.519051	1.519771	1.520492	1.521212	1.521934
96	1.522656	1.523378	1.524100	1.524823	1.525546	1.526269	1.526993	1.527717	1.528441	1.529166
97	1.529891	1.530616	1.531342	1.532068	1.532794	1.533521	1.534248	1.534976	1.535704	1.536432
98	1.537161	1.537889	1.538618	1.539347	1.540076	1.540806	1.541536	1.542267	1.542998	1.543730
99	1.544462	1.545194	1.545926	1.546659	1.547392	1.548127	1.548861	1.549595	1.550329	1.551064
100	1.551800									

TABLE 13.—Density of Solutions of Sulphuric Acid (H_2SO_4) at 20°C

[Calculated from Dr. J. Domke's table.^a Adopted as the basis for standardization of hydrometers indicating per cent of sulphuric acid at 20°C]

Per Cent H_2SO_4	$D_{40}^{20} \text{C}$	Per Cent H_2SO_4	$D_{40}^{20} \text{C}$	Per Cent H_2SO_4	$D_{40}^{20} \text{C}$
0	0.99823	50	1.39505	91.0	1.81950
1	1.00506	51	1.40487	91.2	1.82045
2	1.01178	52	1.41481	91.4	1.82137
3	1.01839	53	1.42487	91.6	1.82227
4	1.02500	54	1.43503	91.8	1.82315
5	1.03168	55	1.44530	92.0	1.82401
6	1.03843	56	1.45568	92.2	1.82484
7	1.04527	57	1.46615	92.4	1.82564
8	1.05216	58	1.47673	92.6	1.82641
9	1.05909	59	1.48740	92.8	1.82717
10	1.06609	60	1.49818	93.0	1.82790
11	1.07314	61	1.50904	93.2	1.82860
12	1.08026	62	1.51993	93.4	1.82928
13	1.08744	63	1.53102	93.6	1.82993
14	1.09468	64	1.54213	93.8	1.83055
15	1.10199	65	1.55333	94.0	1.83115
16	1.10936	66	1.56460	94.2	1.83172
17	1.11679	67	1.57595	94.4	1.83226
18	1.12428	68	1.58739	94.6	1.83276
19	1.13183	69	1.59890	94.8	1.83324
20	1.13943	70	1.61048	95.0	1.83368
21	1.14709	71	1.62213	95.1	1.83389
22	1.15480	72	1.63384	95.2	1.83410
23	1.16258	73	1.64560	95.3	1.83430
24	1.17041	74	1.65738	95.4	1.83449
25	1.17830	75	1.66917	95.5	1.83469
26	1.18624	76	1.68095	95.6	1.83486
27	1.19423	77	1.69268	95.7	1.83503
28	1.20227	78	1.70433	95.8	1.83520
29	1.21036	79	1.71585	95.9	1.83534
30	1.21850	80	1.72717	96.0	1.83548
31	1.22669	81	1.73827	96.1	1.83560
32	1.23492	82	1.74904	96.2	1.83572
33	1.24320	83	1.75943	96.3	1.83584
34	1.25154	84	1.76932	96.4	1.83594
35	1.25992	85	1.77860	96.5	1.83604
36	1.26836	85.5	1.78300	96.6	1.83613
37	1.27685	86	1.78721	96.7	1.83621
38	1.28543	86.5	1.79124	96.8	1.83628
39	1.29407	87	1.79509	96.9	1.83634
40	1.30278	87.5	1.79875	97.0	1.83637
41	1.31157	88	1.80223	97.1	1.83639
42	1.32043	88.5	1.80552	97.2	1.83640
43	1.32938	89	1.80864	97.3	1.83640
44	1.33843	89.5	1.81159	97.4	1.83639
45	1.34759	90	1.81438	97.5	1.83637
46	1.35686	90.2	1.81545	97.6	1.83634
47	1.36625	90.4	1.81650	97.7	1.83629
48	1.37574	90.6	1.81753	97.8	1.83623
49	1.38533	90.8	1.81853	97.9	1.83615
50	1.39505	91.0	1.81950	98.0	1.83605

^a Wiss. Abh. der Kaiserlichen Normal-Messungs-Kommission, 5, p. 131; 1900.

TABLE 14.—Temperature Corrections to Per Cent of Sulphuric Acid Determined by Hydrometer (Standard at 20° C)

[Calculated from the same data as the preceding table, assuming Jena 16^{III} glass as the material used. The table should be used with caution, and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Observed Per Cent H ₂ SO ₄	Temperature in Degrees Centigrade											
	0	5	10	15	25	30	35	40	45	50	55	60
	Subtract from Observed Per Cent				Add to Observed Per Cent							
0					0.16	0.35	0.59	0.86	1.17	1.5	1.9	2.1
5	0.59	0.49	0.36	0.20	0.24	0.50	0.79	1.11	1.45	1.8	2.2	2.6
10	0.92	0.72	0.51	0.27	0.29	0.60	0.93	1.28	1.65	2.0	2.4	2.8
20	1.39	1.06	0.72	0.36	0.37	0.75	1.14	1.53	1.93	2.3	2.7	3.1
30	1.64	1.23	0.82	0.41	0.41	0.82	1.24	1.65	2.07	2.5	2.9	3.3
40	1.65	1.24	0.82	0.41	0.41	0.82	1.22	1.62	2.03	2.4	2.8	3.2
50	1.56	1.17	0.78	0.39	0.38	0.77	1.15	1.52	1.90	2.3	2.6	3.0
60	1.52	1.14	0.76	0.38	0.37	0.74	1.11	1.48	1.84	2.2	2.6	2.9
70	1.54	1.15	0.76	0.38	0.38	0.75	1.13	1.50	1.86	2.2	2.6	3.0
80	1.72	1.30	0.87	0.44	0.45	0.90	1.36	1.83	2.31	2.8	3.3	3.8
81	1.76	1.34	0.92	0.44	0.47	0.93	1.42	1.93	2.44	3.0	3.5	4.0
82	1.84	1.41	0.96	0.47	0.50	1.00	1.51	2.04	2.58	3.1	3.7	4.3
83	1.94	1.48	1.00	0.50	0.53	1.06	1.59	2.18	2.78	3.4	4.0	4.6
84	2.05	1.57	1.06	0.53	0.55	1.12	1.74	2.36	3.0	3.7	4.4	5.1
85	2.20	1.67	1.13	0.57	0.61	1.23	1.88	2.57	3.3	4.0	4.9	5.8
86	2.36	1.80	1.22	0.62	0.66	1.35	2.08	2.84	3.7	4.6	5.5	
87	2.54	1.95	1.32	0.67	0.73	1.50	2.31	3.2	4.1	5.2		
88	2.75	2.12	1.44	0.74	0.81	1.67	2.59	3.6	4.7	6.0		
89	3.01	2.31	1.58	0.82	0.89	1.86	2.91	4.1	5.6			
90	3.27	2.53	1.73	0.91	0.99	2.10	3.4	4.9				
91	3.57	2.78	1.93	1.01	1.13	2.44	4.1					
92	3.91	3.06	2.13	1.12	1.32	3.00						
93	4.29	3.38	2.37	1.26	1.64							
94	4.75	3.77	2.69	1.46								
95	5.29	4.26	3.12	1.76								
96	5.96	4.88	3.65	2.19								
97	6.78	5.68	4.42	2.90								

TABLE 15.—Temperature Corrections to Readings of Specific Gravity Hydrometers in American Petroleum Oils at Various Temperatures

[Standard at 60°/60° F]

Observed Temperature °F	Observed Specific Gravity						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
	Subtract from Observed Specific Gravity						
30	0.016	0.015	0.014	0.012	0.011	0.011	0.011
32	.015	.014	.013	.012	.011	.010	.010
34	.014	.013	.012	.011	.010	.010	.010
36	.013	.012	.011	.010	.009	.009	.009
38	.012	.011	.010	.009	.008	.008	.008
40	.0105	.0095	.0090	.0080	.0075	.0070	.0070
42	.0095	.0085	.0080	.0070	.0065	.0065	.0065
44	.0085	.0075	.0070	.0065	.0060	.0060	.0055
46	.0075	.0065	.0060	.0055	.0050	.0050	.0050
48	.0065	.0060	.0055	.0050	.0045	.0045	.0040
50	.0050	.0050	.0045	.0040	.0035	.0035	.0035
52	.0040	.0040	.0035	.0030	.0030	.0030	.0030
54	.0030	.0030	.0025	.0025	.0020	.0020	.0020
56	.0020	.0020	.0020	.0015	.0015	.0015	.0015
58	.0010	.0010	.0010	.0005	.0005	.0005	.0005
Add to Observed Specific Gravity							
60	.0000	.0000	.0000	.0000	.0000	.0000	.0000
62	.0010	.0010	.0010	.0005	.0005	.0005	
64	.0020	.0020	.0015	.0015	.0015	.0015	
66	.0030	.0030	.0025	.0025	.0020	.0020	
68	.0040	.0040	.0035	.0030	.0030	.0030	
70	.0050	.0050	.0045	.0040	.0040	.0035	
72	.0060	.0055	.0050	.0045	.0045	.0040	
74	.0070	.0065	.0060	.0055	.0050	.0050	
76	.0080	.0075	.0070	.0065	.0060	.0055	
78	.0090	.0085	.0080	.0070	.0065	.0065	
80	.010	.009	.008	.008	.007	.007	
82	.011	.010	.009	.008	.008	.007	
84	.012	.011	.010	.009	.009	.008	
86	.013	.012	.011	.010	.009	.009	
88	.014	.013	.012	.011	.010	.010	
90	.015	.014	.013	.012	.011	.010	
92	.016	.015	.013	.012	.011	.011	
94	.017	.016	.014	.013	.012	.012	
96	.018	.016	.015	.014	.013	.013	
98	.019	.017	.016	.015	.014	.013	
100	.020	.018	.017	.015	.014	.014	
102	.021	.019	.018	.016	.015	.015	
104	.022	.020	.018	.017	.016	.015	
106	.023	.021	.019	.017	.016	.016	
108	.024	.022	.020	.018	.017	.017	
110	.025	.023	.021	.019	.018	.017	
112	.026	.024	.022	.020	.019	.018	
114	.027	.025	.022	.020	.019	.019	
116	.028	.026	.023	.021	.020	.019	
118	.029	.026	.024	.022	.021	.020	
120	.030	.027	.025	.023	.022	.021	

(This table is calculated from the same data as Table I, Circular No. 57, Bureau of Standards.)

TABLE 16.—Temperature Corrections to Readings of Baumé Hydrometers in American Petroleum Oils at Various Temperatures

[Standard at 60° F; Modulus 140]

Observed Temperature ° F	Observed Degrees Baumé							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	Add to Observed Degrees Baumé							
30	1.7	2.0	2.4	3.0	3.7	4.3	5.0	5.7
32	1.6	1.9	2.3	2.8	3.4	4.0	4.7	5.3
34	1.5	1.8	2.1	2.6	3.1	3.7	4.3	4.9
36	1.4	1.6	2.0	2.4	2.9	3.4	4.0	4.6
38	1.3	1.5	1.8	2.2	2.6	3.1	3.6	4.2
40	1.2	1.4	1.6	2.0	2.4	2.8	3.2	3.8
42	1.1	1.2	1.5	1.8	2.2	2.5	2.9	3.4
44	.9	1.1	1.3	1.6	2.0	2.2	2.6	3.0
46	.8	.9	1.1	1.4	1.7	1.9	2.3	2.7
48	.7	.8	.9	1.2	1.4	1.6	2.0	2.3
50	.6	.7	.8	1.0	1.2	1.4	1.6	1.9
52	.5	.6	.7	.8	1.0	1.1	1.3	1.5
54	.3	.4	.5	.6	.8	.9	1.0	1.1
56	.2	.3	.3	.4	.5	.6	.6	.7
58	.1	.1	.1	.2	.3	.3	.3	.4
	Subtract from Observed Degrees Baumé							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
60	.0	.0	.0	.0	.0	.0	.0	.0
62	.1	.1	.1	.2	.2	.3	.3	.4
64	.2	.3	.3	.4	.4	.6	.6	.7
66	.3	.4	.5	.6	.7	.8	.9	1.0
68	.5	.6	.6	.7	.9	1.1	1.3	1.4
70	.6	.7	.8	.9	1.1	1.4	1.6	1.7
72	.7	.8	.9	1.1	1.3	1.6	1.9	2.1
74	.8	.9	1.1	1.3	1.6	1.8	2.2	2.5
76	.9	1.1	1.3	1.5	1.8	2.1	2.5	2.8
78	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.1
80	1.1	1.3	1.5	1.8	2.2	2.6	3.1	3.5
82	1.2	1.4	1.7	2.0	2.5	2.9	3.4	3.9
84	1.3	1.5	1.8	2.2	2.7	3.2	3.7	4.3
86	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6
88	1.6	1.8	2.1	2.6	3.1	3.7	4.2	4.9
90	1.7	2.0	2.3	2.7	3.3	3.9	4.5	5.2
92	1.8	2.1	2.4	2.9	3.5	4.2	4.9	5.6
94	1.9	2.2	2.6	3.1	3.8	4.4	5.1	5.9
96	2.0	2.3	2.7	3.3	4.0	4.6	5.4	6.3
98	2.1	2.4	2.9	3.4	4.2	4.9	5.7	6.6
100	2.2	2.6	3.0	3.6	4.4	5.1	6.0	6.9
102	2.3	2.7	3.2	3.8	4.6	5.4	6.3	7.2
104	2.4	2.9	3.3	4.0	4.8	5.7	6.6	7.5
106	2.5	3.0	3.5	4.2	5.0	5.9	6.9	7.9
108	2.7	3.1	3.6	4.3	5.2	6.2	7.2	8.2
110	2.8	3.2	3.7	4.4	5.4	6.4	7.5	8.5
112	2.9	3.3	3.9	4.6	5.6	6.7	7.7	8.8
114	3.0	3.4	4.0	4.7	5.8	6.9	7.9	9.1
116	3.1	3.6	4.1	4.9	6.0	7.1	8.2	9.4
118	3.2	3.7	4.3	5.1	6.2	7.3	8.5	9.8
120	3.3	3.8	4.4	5.3	6.4	7.5	8.8	10.1

(This table is calculated from the same data as Table II, Circular No. 57, Bureau of Standards.)

17024°—16—5

TABLE 17.—Degrees Baumé, Pounds per Gallon, and Gallons per Pound Corresponding to Various Specific Gravities

Specific Gravity 60°/60° F	Degrees Baumé (Modulus 140)	Pounds per Gallon	Gallons per Pound
0.600	103.33	4.993	0.2003
.610	99.51	5.076	.1970
.620	95.81	5.160	.1938
.630	92.22	5.243	.1907
.640	88.75	5.326	.1877
.650	85.38	5.410	.1848
.660	82.12	5.493	.1820
.670	78.96	5.577	.1793
.680	75.88	5.660	.1767
.690	72.90	5.743	.1741
.700	70.00	5.827	.1716
.710	67.18	5.910	.1692
.720	64.44	5.994	.1668
.730	61.78	6.077	.1646
.740	59.19	6.160	.1623
.750	56.67	6.244	.1602
.760	54.21	6.327	.1580
.770	51.82	6.410	.1560
.780	49.49	6.494	.1540
.790	47.22	6.577	.1520
.800	45.00	6.661	.1501
.810	42.84	6.744	.1483
.820	40.73	6.827	.1465
.830	38.68	6.911	.1447
.840	36.67	6.994	.1430
.850	34.71	7.078	.1413
.860	32.79	7.161	.1396
.870	30.92	7.244	.1380
.880	29.09	7.328	.1365
.890	27.30	7.411	.1349
.900	25.56	7.494	.1334
.910	23.85	7.578	.1320
.920	22.17	7.661	.1305
.930	20.54	7.745	.1291
.940	18.94	7.828	.1278
.950	17.37	7.911	.1264
.960	15.83	7.995	.1251
.970	14.33	8.078	.1238
.980	12.86	8.162	.1225
.990	11.41	8.245	.1213
1.000	10.00	8.328	.1201

(See Circular No. 57 for more complete tables.)

TABLE 18.—Specific Gravities, Pounds per Gallon, and Gallons per Pound Corresponding to Various Degrees Baumé

Degrees Baumé (Modulus 140)	Specific Gravity 60°/60° F	Pounds per Gallon	Gallons per Pound	Degrees Baumé (Modulus 140)	Specific Gravity 60°/60° F	Pounds per Gallon	Gallons per Pound
10.0	1.0000	8.328	0.1201	55.0	0.7568	6.300	0.1587
11.0	.9929	8.269	.1209	56.0	.7527	6.266	.1596
12.0	.9859	8.211	.1218	57.0	.7487	6.233	.1604
13.0	.9790	8.153	.1227	58.0	.7447	6.199	.1613
14.0	.9722	8.096	.1235	59.0	.7407	6.166	.1622
15.0	.9655	8.041	.1244	60.0	.7368	6.134	.1630
16.0	.9589	7.986	.1252	61.0	.7330	6.102	.1639
17.0	.9524	7.931	.1261	62.0	.7292	6.070	.1647
18.0	.9459	7.877	.1270	63.0	.7254	6.038	.1656
19.0	.9396	7.825	.1278	64.0	.7216	6.007	.1665
20.0	.9333	7.772	.1287	65.0	.7179	5.976	.1673
21.0	.9272	7.721	.1295	66.0	.7143	5.946	.1682
22.0	.9211	7.670	.1304	67.0	.7107	5.916	.1690
23.0	.9150	7.620	.1313	68.0	.7071	5.886	.1699
24.0	.9091	7.570	.1321	69.0	.7035	5.856	.1708
25.0	.9032	7.522	.1330	70.0	.7000	5.827	.1716
26.0	.8974	7.473	.1338	71.0	.6965	5.798	.1725
27.0	.8917	7.425	.1347	72.0	.6931	5.769	.1733
28.0	.8861	7.378	.1355	73.0	.6897	5.741	.1742
29.0	.8805	7.332	.1364	74.0	.6863	5.712	.1751
30.0	.8750	7.286	.1373	75.0	.6829	5.685	.1759
31.0	.8696	7.241	.1381	76.0	.6796	5.657	.1768
32.0	.8642	7.196	.1390	77.0	.6763	5.629	.1776
33.0	.8589	7.152	.1398	78.0	.6731	5.602	.1785
34.0	.8537	7.108	.1407	79.0	.6699	5.576	.1793
35.0	.8485	7.065	.1415	80.0	.6667	5.549	.1802
36.0	.8434	7.022	.1424	81.0	.6635	5.522	.1811
37.0	.8383	6.980	.1433	82.0	.6604	5.497	.1819
38.0	.8333	6.939	.1441	83.0	.6573	5.471	.1828
39.0	.8284	6.898	.1450	84.0	.6542	5.445	.1837
40.0	.8235	6.857	.1459	85.0	.6512	5.420	.1845
41.0	.8187	6.817	.1467	86.0	.6482	5.395	.1854
42.0	.8140	6.777	.1476	87.0	.6452	5.370	.1862
43.0	.8092	6.738	.1484	88.0	.6422	5.345	.1871
44.0	.8046	6.699	.1493	89.0	.6393	5.320	.1880
45.0	.8000	6.661	.1501	90.0	.6364	5.296	.1888
46.0	.7955	6.623	.1510	91.0	.6335	5.272	.1897
47.0	.7910	6.586	.1518	92.0	.6306	5.248	.1905
48.0	.7865	6.548	.1527	93.0	.6278	5.225	.1914
49.0	.7821	6.511	.1536	94.0	.6250	5.201	.1923
50.0	.7778	6.476	.1544	95.0	.6222	5.178	.1931
51.0	.7735	6.440	.1553	96.0	.6195	5.155	.1940
52.0	.7692	6.404	.1562	97.0	.6167	5.132	.1949
53.0	.7650	6.369	.1570	98.0	.6140	5.110	.1957
54.0	.7609	6.334	.1579	99.0	.6114	5.088	.1966
55.0	.7568	6.300	.1587	100.0	.6087	5.066	.1974

(See Circular No. 57 for more complete tables.)

TABLE 19.—Degrees Baumé Corresponding to Specific Gravities at 60° F (15.56° C)
for Liquids Heavier than Water

[Calculated from the formula degrees Baumé = $145 - \frac{145}{D_{60^{\circ}F}}$, which defines the Baumé scale, in general use in the United States, for liquids heavier than water]

D 15.56° C 60° F	0	1	2	3	4	5	6	7	8	9	Diff.
1.00	0.000	0.145	0.289	0.434	0.578	0.721	0.865	1.008	1.151	1.293	143
1.01	1.436	1.578	1.719	1.861	2.002	2.143	2.283	2.424	2.564	2.704	141
1.02	2.843	2.982	3.121	3.260	3.399	3.537	3.675	3.812	3.950	4.087	138
1.03	4.223	4.360	4.496	4.632	4.768	4.903	5.038	5.174	5.308	5.443	136
1.04	5.577	5.711	5.845	5.978	6.111	6.244	6.377	6.509	6.641	6.773	133
1.05	6.905	7.036	7.167	7.298	7.429	7.559	7.689	7.819	7.949	8.078	130
1.06	8.208	8.336	8.465	8.594	8.722	8.850	8.978	9.105	9.232	9.359	128
1.07	9.486	9.613	9.739	9.865	9.991	10.116	10.242	10.367	10.492	10.616	126
1.08	10.741	10.865	10.989	11.113	11.236	11.359	11.483	11.605	11.728	11.850	124
1.09	11.972	12.094	12.216	12.338	12.459	12.580	12.701	12.821	12.942	13.062	121
1.10	13.182	13.302	13.421	13.540	13.659	13.778	13.897	14.015	14.134	14.252	119
1.11	14.370	14.487	14.604	14.721	14.838	14.955	15.072	15.188	15.304	15.420	117
1.12	15.536	15.651	15.767	15.882	15.997	16.111	16.226	16.340	16.454	16.568	115
1.13	16.682	16.795	16.908	17.021	17.134	17.247	17.359	17.471	17.583	17.695	113
1.14	17.807	17.919	18.030	18.141	18.252	18.363	18.473	18.583	18.693	18.803	111
1.15	18.913	19.023	19.132	19.241	19.350	19.459	19.568	19.676	19.784	19.892	109
1.16	20.000	20.108	20.215	20.322	20.430	20.536	20.643	20.750	20.856	20.962	107
1.17	21.068	21.174	21.280	21.385	21.491	21.596	21.701	21.806	21.910	22.014	105
1.18	22.119	22.223	22.327	22.430	22.534	22.637	22.740	22.843	22.946	23.049	103
1.19	23.151	23.254	23.356	23.458	23.560	23.661	23.763	23.864	23.965	24.066	101
1.20	24.167	24.267	24.368	24.468	24.568	24.668	24.768	24.868	24.967	25.066	100
1.21	25.165	25.264	25.363	25.462	25.560	25.658	25.755	25.855	25.952	26.050	98
1.22	26.148	26.245	26.342	26.439	26.536	26.633	26.729	26.826	26.922	27.018	97
1.23	27.114	27.210	27.305	27.401	27.496	27.591	27.686	27.781	27.876	27.970	95
1.24	28.065	28.159	28.253	28.347	28.441	28.534	28.628	28.721	28.814	28.907	94
1.25	29.000	29.093	29.185	29.278	29.370	29.462	29.554	29.646	29.738	29.829	92
1.26	29.921	30.012	30.103	30.194	30.285	30.376	30.466	30.556	30.647	30.737	91
1.27	30.827	30.917	31.006	31.096	31.185	31.275	31.364	31.453	31.542	31.630	89
1.28	31.719	31.807	31.896	31.984	32.072	32.160	32.247	32.335	32.422	32.510	88
1.29	32.597	32.684	32.771	32.858	32.944	33.031	33.117	33.204	33.290	33.376	87
1.30	33.462	33.547	33.633	33.718	33.804	33.889	33.974	34.059	34.144	34.229	85
1.31	34.313	34.397	34.482	34.566	34.650	34.734	34.818	34.901	34.985	35.068	84
1.32	35.152	35.235	35.318	35.401	35.483	35.566	35.649	35.731	35.813	35.895	83
1.33	35.977	36.059	36.141	36.223	36.304	36.386	36.467	36.548	36.629	36.710	81
1.34	36.791	36.872	36.952	37.033	37.113	37.193	37.273	37.353	37.433	37.513	80
1.35	37.593	37.672	37.751	37.831	37.910	37.989	38.068	38.147	38.225	38.304	79
1.36	38.382	38.461	38.539	38.617	38.695	38.773	38.851	38.928	39.006	39.083	78
1.37	39.161	39.238	39.315	39.392	39.469	39.546	39.622	39.699	39.775	39.851	77
1.38	39.928	40.004	40.080	40.156	40.231	40.307	40.382	40.458	40.533	40.608	76
1.39	40.683	40.758	40.833	40.908	40.983	41.057	41.132	41.206	41.280	41.355	75
1.40	41.429	41.503	41.576	41.650	41.724	41.797	41.871	41.944	42.017	42.090	74
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73

TABLE 19.—Degrees Baumé Corresponding to Specific Gravities at 60° F (15.56° C) for Liquids Heavier than Water—Continued

D 15.56° C 15.56°	0	1	2	3	4	5	6	7	8	9	Diff.
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73
1.42	42.887	42.959	43.031	43.103	43.174	43.246	43.317	43.388	43.459	43.530	72
1.43	43.601	43.672	43.743	43.814	43.884	43.955	44.025	44.095	44.166	44.236	71
1.44	44.306	44.376	44.445	44.515	44.585	44.654	44.724	44.793	44.862	44.931	70
1.45	45.000	45.069	45.138	45.207	45.275	45.344	45.412	45.481	45.549	45.617	69
1.46	45.685	45.753	45.821	45.889	45.956	46.024	46.091	46.159	46.226	46.293	67
1.47	46.361	46.428	46.495	46.562	46.628	46.695	46.762	46.828	46.894	46.961	67
1.48	47.027	47.093	47.159	47.225	47.291	47.357	47.423	47.488	47.554	47.619	66
1.49	47.685	47.750	47.815	47.880	47.945	48.010	48.075	48.140	48.204	48.269	65
1.50	48.333	48.398	48.462	48.526	48.591	48.655	48.719	48.782	48.846	48.910	64
1.51	48.974	49.037	49.101	49.164	49.227	49.290	49.354	49.417	49.480	49.543	63
1.52	49.605	49.668	49.731	49.793	49.856	49.918	49.980	50.043	50.105	50.167	62
1.53	50.229	50.291	50.353	50.414	50.476	50.538	50.599	50.660	50.722	50.783	61
1.54	50.844	50.905	50.966	51.027	51.088	51.149	51.210	51.270	51.331	51.391	61
1.55	51.452	51.512	51.572	51.632	51.692	51.752	51.812	51.872	51.932	51.992	60
1.56	52.051	52.111	52.170	52.230	52.289	52.348	52.407	52.467	52.526	52.585	59
1.57	52.643	52.702	52.761	52.820	52.878	52.937	52.995	53.053	53.112	53.170	59
1.58	53.228	53.286	53.344	53.402	53.460	53.517	53.575	53.633	53.690	53.748	58
1.59	53.805	53.862	53.920	53.977	54.034	54.091	54.148	54.205	54.262	54.318	57
1.60	54.375	54.432	54.488	54.545	54.601	54.657	54.714	54.770	54.826	54.882	56
1.61	54.938	54.994	55.050	55.106	55.161	55.217	55.272	55.328	55.383	55.439	56
1.62	55.494	55.549	55.604	55.659	55.714	55.769	55.824	55.879	55.934	55.988	55
1.63	56.043	56.098	56.152	56.206	56.261	56.315	56.369	56.423	56.478	56.531	54
1.64	56.585	56.639	56.693	56.747	56.801	56.854	56.908	56.961	57.015	57.068	54
1.65	57.121	57.175	57.228	57.281	57.334	57.387	57.440	57.493	57.545	57.598	53
1.66	57.651	57.703	57.756	57.808	57.861	57.913	57.965	58.017	58.070	58.122	52
1.67	58.174	58.226	58.278	58.329	58.381	58.433	58.485	58.536	58.588	58.639	52
1.68	58.690	58.742	58.793	58.844	58.896	58.947	58.998	59.049	59.100	59.150	51
1.69	59.201	59.252	59.303	59.353	59.404	59.454	59.505	59.555	59.605	59.656	50
1.70	59.706	59.756	59.806	59.856	59.906	59.956	60.006	60.056	60.105	60.155	50
1.71	60.205	60.254	60.304	60.353	60.403	60.452	60.501	60.550	60.600	60.649	49
1.72	60.698	60.747	60.796	60.844	60.893	60.942	60.991	61.039	61.088	61.136	49
1.73	61.185	61.234	61.282	61.330	61.378	61.427	61.475	61.523	61.571	61.619	48
1.74	61.667	61.715	61.762	61.810	61.858	61.906	61.953	62.001	62.048	62.096	48
1.75	62.143	62.190	62.237	62.285	62.332	62.379	62.426	62.473	62.520	62.567	47
1.76	62.614	62.660	62.707	62.754	62.801	62.847	62.894	62.940	62.987	63.033	46
1.77	63.079	63.125	63.172	63.218	63.264	63.310	63.356	63.402	63.448	63.494	46
1.78	63.539	63.585	63.631	63.676	63.722	63.768	63.813	63.858	63.904	63.949	46
1.79	63.994	64.040	64.085	64.130	64.175	64.220	64.265	64.310	64.355	64.400	45
1.80	64.445	64.489	64.534	64.579	64.623	64.668	64.712	64.757	64.801	64.845	45
1.81	64.890	64.934	64.978	65.022	65.066	65.110	65.154	65.198	65.242	65.286	44
1.82	65.330	65.374	65.417	65.461	65.504	65.548	65.591	65.635	65.678	65.722	43
1.83	65.765	65.808	65.852	65.895	65.938	65.981	66.024	66.067	66.110	66.153	43
1.84	66.196	66.238	66.281	66.324	66.367	66.409	66.452	66.494	66.537	66.579	42
1.85	66.622										

TABLE 20.—Specific Gravities at 60°F (15°C) Corresponding to Degrees Baumé for Liquids Heavier than Water

[Calculated from the formula specific gravity $60^{\circ}\text{F} = \frac{145}{145 - \text{Deg. Baumé.}}$]

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	1.0007	1.0014	1.0021	1.0028	1.0035	1.0042	1.0049	1.0055	1.0062
1	1.0069	1.0076	1.0083	1.0090	1.0097	1.0105	1.0112	1.0119	1.0126	1.0133
2	1.0140	1.0147	1.0154	1.0161	1.0168	1.0175	1.0183	1.0190	1.0197	1.0204
3	1.0211	1.0218	1.0226	1.0233	1.0240	1.0247	1.0255	1.0262	1.0269	1.0276
4	1.0284	1.0291	1.0298	1.0306	1.0313	1.0320	1.0328	1.0335	1.0342	1.0350
5	1.0357	1.0365	1.0372	1.0379	1.0387	1.0394	1.0402	1.0409	1.0417	1.0424
6	1.0432	1.0439	1.0447	1.0454	1.0462	1.0469	1.0477	1.0484	1.0492	1.0500
7	1.0507	1.0515	1.0522	1.0530	1.0538	1.0545	1.0553	1.0561	1.0569	1.0576
8	1.0584	1.0592	1.0599	1.0607	1.0615	1.0623	1.0630	1.0638	1.0646	1.0654
9	1.0662	1.0670	1.0677	1.0685	1.0693	1.0701	1.0709	1.0717	1.0725	1.0733
10	1.0741	1.0749	1.0757	1.0765	1.0773	1.0781	1.0789	1.0797	1.0805	1.0813
11	1.0821	1.0829	1.0837	1.0845	1.0853	1.0861	1.0870	1.0878	1.0886	1.0894
12	1.0902	1.0910	1.0919	1.0927	1.0935	1.0943	1.0952	1.0960	1.0968	1.0977
13	1.0985	1.0993	1.1002	1.1010	1.1018	1.1027	1.1035	1.1043	1.1052	1.1060
14	1.1069	1.1077	1.1086	1.1094	1.1103	1.1111	1.1120	1.1128	1.1137	1.1145
15	1.1154	1.1162	1.1171	1.1180	1.1188	1.1197	1.1206	1.1214	1.1223	1.1232
16	1.1240	1.1249	1.1258	1.1267	1.1275	1.1284	1.1293	1.1302	1.1310	1.1319
17	1.1328	1.1337	1.1346	1.1355	1.1364	1.1373	1.1381	1.1390	1.1399	1.1408
18	1.1417	1.1426	1.1435	1.1444	1.1453	1.1462	1.1472	1.1481	1.1490	1.1499
19	1.1508	1.1517	1.1526	1.1535	1.1545	1.1554	1.1563	1.1572	1.1581	1.1591
20	1.1600	1.1609	1.1619	1.1628	1.1637	1.1647	1.1656	1.1665	1.1675	1.1684
21	1.1694	1.1703	1.1712	1.1722	1.1731	1.1741	1.1750	1.1760	1.1769	1.1779
22	1.1789	1.1798	1.1808	1.1817	1.1827	1.1837	1.1846	1.1856	1.1866	1.1876
23	1.1885	1.1895	1.1905	1.1915	1.1924	1.1934	1.1944	1.1954	1.1964	1.1974
24	1.1983	1.1993	1.2003	1.2013	1.2023	1.2033	1.2043	1.2053	1.2063	1.2073
25	1.2083	1.2093	1.2104	1.2114	1.2124	1.2134	1.2144	1.2154	1.2164	1.2175
26	1.2185	1.2195	1.2205	1.2216	1.2226	1.2236	1.2247	1.2257	1.2268	1.2278
27	1.2288	1.2299	1.2309	1.2319	1.2330	1.2340	1.2351	1.2361	1.2372	1.2383
28	1.2393	1.2404	1.2414	1.2425	1.2436	1.2446	1.2457	1.2468	1.2478	1.2489
29	1.2500	1.2511	1.2522	1.2532	1.2543	1.2554	1.2565	1.2576	1.2587	1.2598
30	1.2609	1.2620	1.2631	1.2642	1.2653	1.2664	1.2675	1.2686	1.2697	1.2708
31	1.2719	1.2730	1.2742	1.2753	1.2764	1.2775	1.2787	1.2798	1.2809	1.2821
32	1.2832	1.2843	1.2855	1.2866	1.2877	1.2889	1.2900	1.2912	1.2923	1.2935
33	1.2946	1.2958	1.2970	1.2981	1.2993	1.3004	1.3016	1.3028	1.3040	1.3051
34	1.3063	1.3075	1.3087	1.3098	1.3110	1.3122	1.3134	1.3146	1.3158	1.3170
35	1.3182	1.3194	1.3206	1.3218	1.3230	1.3242	1.3254	1.3266	1.3278	1.3291
36	1.3303	1.3315	1.3327	1.3339	1.3352	1.3364	1.3376	1.3389	1.3401	1.3414
37	1.3426	1.3438	1.3451	1.3463	1.3476	1.3488	1.3501	1.3514	1.3526	1.3539
38	1.3551	1.3564	1.3577	1.3590	1.3602	1.3615	1.3628	1.3641	1.3653	1.3666
39	1.3679	1.3692	1.3705	1.3718	1.3731	1.3744	1.3757	1.3770	1.3783	1.3796
40	1.3810	1.3823	1.3836	1.3849	1.3862	1.3876	1.3889	1.3902	1.3916	1.3929
41	1.3942	1.3956	1.3969	1.3983	1.3996	1.4010	1.4023	1.4037	1.4050	1.4064
42	1.4078	1.4091	1.4105	1.4119	1.4133	1.4146	1.4160	1.4174	1.4188	1.4202
43	1.4216	1.4230	1.4244	1.4258	1.4272	1.4286	1.4300	1.4314	1.4328	1.4342
44	1.4356	1.4371	1.4385	1.4399	1.4414	1.4428	1.4442	1.4457	1.4471	1.4486
45	1.4500	1.4515	1.4529	1.4544	1.4558	1.4573	1.4588	1.4602	1.4617	1.4632
46	1.4646	1.4661	1.4676	1.4691	1.4706	1.4721	1.4736	1.4751	1.4766	1.4781
47	1.4796	1.4811	1.4826	1.4841	1.4857	1.4872	1.4887	1.4902	1.4918	1.4933
48	1.4948	1.4964	1.4979	1.4995	1.5010	1.5026	1.5041	1.5057	1.5073	1.5088
49	1.5104	1.5120	1.5136	1.5152	1.5167	1.5183	1.5199	1.5215	1.5231	1.5247
50	1.5263	1.5279	1.5295	1.5312	1.5328	1.5344	1.5360	1.5376	1.5393	1.5409
51	1.5426	1.5442	1.5458	1.5475	1.5491	1.5508	1.5525	1.5541	1.5558	1.5575
52	1.5591	1.5608	1.5625	1.5642	1.5659	1.5676	1.5693	1.5710	1.5727	1.5744
53	1.5761	1.5778	1.5795	1.5812	1.5830	1.5847	1.5864	1.5882	1.5899	1.5917
54	1.5934	1.5952	1.5969	1.5987	1.6004	1.6022	1.6040	1.6058	1.6075	1.6093
55	1.6111	1.6129	1.6147	1.6165	1.6183	1.6201	1.6219	1.6237	1.6256	1.6274
56	1.6292	1.6310	1.6329	1.6347	1.6366	1.6384	1.6403	1.6421	1.6440	1.6459
57	1.6477	1.6496	1.6515	1.6534	1.6553	1.6571	1.6590	1.6609	1.6628	1.6648
58	1.6667	1.6686	1.6705	1.6724	1.6744	1.6763	1.6782	1.6802	1.6821	1.6841
59	1.6860	1.6880	1.6900	1.6919	1.6939	1.6959	1.6979	1.6999	1.7019	1.7039
60	1.7059	1.7079	1.7099	1.7119	1.7139	1.7160	1.7180	1.7200	1.7221	1.7241
61	1.7262	1.7282	1.7303	1.7324	1.7344	1.7365	1.7386	1.7407	1.7428	1.7449
62	1.7470	1.7491	1.7512	1.7533	1.7554	1.7576	1.7597	1.7618	1.7640	1.7661
63	1.7683	1.7705	1.7726	1.7748	1.7770	1.7791	1.7813	1.7835	1.7857	1.7879
64	1.7901	1.7923	1.7946	1.7968	1.7990	1.8012	1.8035	1.8057	1.8080	1.8102
65	1.8125	1.8148	1.8170	1.8193	1.8216	1.8239	1.8262	1.8285	1.8308	1.8331
66	1.8354	1.8378	1.8401	1.8424	1.8448	1.8471	1.8495	1.8519	1.8542	1.8566
67	1.8590	1.8614	1.8638	1.8662	1.8686	1.8710	1.8734	1.8758	1.8782	1.8807
68	1.8831	1.8856	1.8880	1.8905	1.8930	1.8954	1.8979	1.9004	1.9029	1.9054
69	1.9079	1.9104	1.9129	1.9155	1.9180	1.9205	1.9231	1.9256	1.9282	1.9308
70	1.9333									

TABLE 21.—Degrees Baumé Corresponding to Specific Gravities at 60° F (15° C)
for Liquids Lighter than Water

[Calculated from the formula degrees Baumé = $\frac{140}{D_{60^{\circ}F}} - 130$ which defines the Baumé scale, in general use in the United States, for liquids lighter than water]

D 15° C 15° C	0	1	2	3	4	5	6	7	8	9	Diff.
.60	103.333	102.945	102.558	102.172	101.788	101.405	101.023	100.642	100.263	99.885	382
.61	99.508	99.133	98.758	98.385	98.013	97.642	97.273	96.904	96.537	96.171	370
.62	95.806	95.443	95.080	94.719	94.359	94.000	93.642	93.285	92.930	92.576	360
.63	92.222	91.870	91.519	91.169	90.820	90.472	90.126	89.780	89.436	89.092	348
.64	88.750	88.409	88.068	87.729	87.391	87.054	86.718	86.383	86.049	85.716	337
.65	85.385	85.054	84.724	84.395	84.067	83.741	83.415	83.090	82.766	82.443	327
.66	82.121	81.800	81.480	81.161	80.843	80.526	80.210	79.895	79.581	79.268	317
.67	78.955	78.644	78.333	78.024	77.715	77.407	77.101	76.795	76.490	76.186	308
.68	75.882	75.580	75.279	74.978	74.678	74.380	74.082	73.785	73.488	73.193	298
.69	72.899	72.605	72.312	72.020	71.729	71.439	71.149	70.861	70.573	70.286	290
.70	70.000	69.715	69.430	69.146	68.864	68.582	68.300	68.020	67.740	67.461	282
.71	67.183	66.906	66.629	66.354	66.078	65.804	65.531	65.258	64.986	64.715	274
.72	64.444	64.175	63.906	63.638	63.370	63.103	62.837	62.572	62.308	62.044	266
.73	61.781	61.518	61.257	60.996	60.736	60.476	60.217	59.959	59.702	59.445	260
.74	59.189	58.934	58.679	58.425	58.172	57.919	57.668	57.416	57.166	56.916	252
.75	56.667	56.418	56.170	55.923	55.676	55.430	55.185	54.941	54.697	54.453	246
.76	54.210	53.968	53.727	53.486	53.246	53.007	52.768	52.529	52.292	52.055	239
.77	51.818	51.582	51.347	51.113	50.879	50.645	50.412	50.180	49.949	49.718	234
.78	49.487	49.257	49.028	48.799	48.571	48.344	48.117	47.891	47.665	47.440	227
.79	47.215	46.991	46.768	46.545	46.322	46.101	45.879	45.659	45.439	45.219	222
.80	45.000	44.781	44.564	44.346	44.129	43.913	43.697	43.482	43.267	43.053	216
.81	42.840	42.626	42.414	42.202	41.990	41.779	41.569	41.359	41.149	40.940	210
.82	40.732	40.524	40.316	40.109	39.903	39.697	39.492	39.287	39.082	38.878	206
.83	38.675	38.472	38.269	38.067	37.866	37.665	37.464	37.264	37.064	36.866	201
.84	36.667	36.469	36.271	36.074	35.877	35.680	35.485	35.289	35.094	34.900	196
.85	34.706	34.512	34.319	34.127	33.934	33.743	33.551	33.361	33.170	32.980	192
.86	32.791	32.602	32.413	32.225	32.037	31.850	31.663	31.476	31.290	31.105	187
.87	30.920	30.735	30.550	30.366	30.183	30.000	29.817	29.635	29.453	29.272	183
.88	29.091	28.910	28.730	28.550	28.371	28.192	28.014	27.835	27.658	27.480	179
.89	27.303	27.127	26.951	26.775	26.600	26.425	26.250	26.076	25.902	25.729	175
.90	25.556	25.383	25.211	25.039	24.867	24.696	24.525	24.355	24.185	24.015	171
.91	23.846	23.677	23.509	23.341	23.173	23.005	22.838	22.672	22.506	22.339	168
.92	22.174	22.009	21.844	21.679	21.515	21.351	21.188	21.025	20.862	20.700	164
.93	20.538	20.376	20.215	20.054	19.893	19.733	19.573	19.413	19.254	19.095	160
.94	18.936	18.778	18.620	18.462	18.305	18.148	17.991	17.835	17.679	17.524	157
.95	17.368	17.214	17.059	16.905	16.751	16.597	16.444	16.290	16.138	15.985	154
.96	15.833	15.682	15.530	15.379	15.228	15.078	14.928	14.778	14.628	14.479	150
.97	14.330	14.181	14.033	13.885	13.737	13.590	13.443	13.297	13.149	13.003	147
.98	12.857	12.712	12.566	12.421	12.276	12.132	11.988	11.844	11.700	11.557	144
.99	11.414	11.271	11.129	10.987	10.845	10.704	10.562	10.421	10.281	10.140	142
1.00	10.000										

TABLE 22.—Specific Gravities at 60° F (15.56° C) Corresponding to Degrees Baumé for Liquids Lighter than Water[Calculated from the formula, Specific Gravity 60° F = $\frac{140}{130 + \text{Deg. B}^{\circ}}$]

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9964	0.9957	0.9950	0.9943	0.9936
11	.9929	.9922	.9915	.9908	.9901	.9894	.9887	.9880	.9873	.9866
12	.9859	.9852	.9845	.9838	.9831	.9825	.9818	.9811	.9804	.9797
13	.9790	.9783	.9777	.9770	.9763	.9756	.9749	.9743	.9736	.9729
14	.9722	.9715	.9709	.9702	.9695	.9689	.9682	.9675	.9669	.9662
15	.9655	.9649	.9642	.9635	.9629	.9622	.9615	.9609	.9602	.9596
16	.9589	.9582	.9576	.9569	.9563	.9556	.9550	.9543	.9537	.9530
17	.9524	.9517	.9511	.9504	.9498	.9492	.9485	.9479	.9472	.9466
18	.9459	.9453	.9447	.9440	.9434	.9428	.9421	.9415	.9409	.9402
19	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346	.9340
20	.9333	.9327	.9321	.9315	.9309	.9302	.9296	.9290	.9284	.9278
21	.9272	.9265	.9259	.9253	.9247	.9241	.9235	.9229	.9223	.9217
22	.9211	.9204	.9198	.9192	.9186	.9180	.9174	.9168	.9162	.9156
23	.9150	.9144	.9138	.9132	.9126	.9121	.9115	.9109	.9103	.9097
24	.9091	.9085	.9079	.9073	.9067	.9061	.9056	.9050	.9044	.9038
25	.9032	.9026	.9021	.9015	.9009	.9003	.8997	.8992	.8986	.8980
26	.8974	.8969	.8963	.8957	.8951	.8946	.8940	.8934	.8929	.8923
27	.8917	.8912	.8906	.8900	.8895	.8889	.8883	.8878	.8872	.8866
28	.8861	.8855	.8850	.8844	.8838	.8833	.8827	.8822	.8816	.8811
29	.8805	.8799	.8794	.8788	.8783	.8777	.8772	.8766	.8761	.8755
30	.8750	.8745	.8739	.8734	.8728	.8723	.8717	.8712	.8706	.8701
31	.8696	.8690	.8685	.8679	.8674	.8669	.8663	.8658	.8653	.8647
32	.8642	.8637	.8631	.8626	.8621	.8615	.8610	.8605	.8600	.8594
33	.8589	.8584	.8578	.8573	.8568	.8563	.8557	.8552	.8547	.8542
34	.8537	.8531	.8526	.8521	.8516	.8511	.8505	.8500	.8495	.8490
35	.8485	.8480	.8475	.8469	.8464	.8459	.8454	.8449	.8444	.8439
36	.8434	.8429	.8424	.8419	.8413	.8408	.8403	.8398	.8393	.8388
37	.8383	.8378	.8373	.8368	.8363	.8358	.8353	.8348	.8343	.8338
38	.8333	.8328	.8323	.8318	.8314	.8309	.8304	.8299	.8294	.8289
39	.8284	.8279	.8274	.8269	.8264	.8260	.8255	.8250	.8245	.8240
40	.8235	.8230	.8226	.8221	.8216	.8211	.8206	.8202	.8197	.8192
41	.8187	.8182	.8178	.8173	.8168	.8163	.8159	.8154	.8149	.8144
42	.8140	.8135	.8130	.8125	.8121	.8116	.8111	.8107	.8102	.8097
43	.8092	.8088	.8083	.8078	.8074	.8069	.8065	.8060	.8055	.8051
44	.8046	.8041	.8037	.8032	.8028	.8023	.8018	.8014	.8009	.8005
45	.8000	.7995	.7991	.7986	.7982	.7977	.7973	.7968	.7964	.7959
46	.7955	.7950	.7946	.7941	.7937	.7932	.7928	.7923	.7919	.7914
47	.7910	.7905	.7901	.7896	.7892	.7887	.7883	.7878	.7874	.7870
48	.7865	.7861	.7856	.7852	.7848	.7843	.7839	.7834	.7830	.7826
49	.7821	.7817	.7812	.7808	.7804	.7799	.7795	.7791	.7786	.7782
50	.7778	.7773	.7769	.7765	.7761	.7756	.7752	.7748	.7743	.7739
51	.7735	.7731	.7726	.7722	.7718	.7713	.7709	.7705	.7701	.7697
52	.7692	.7688	.7684	.7680	.7675	.7671	.7667	.7663	.7659	.7654
53	.7650	.7646	.7642	.7638	.7634	.7629	.7625	.7621	.7617	.7613
54	.7609	.7605	.7600	.7596	.7592	.7588	.7584	.7580	.7576	.7572
55	.7568	.7563	.7559	.7555	.7551	.7547	.7543	.7539	.7535	.7531

TABLE 22.—Specific Gravities at 60° F (15.56° C) Corresponding to Degrees Baumé for Liquids Lighter than Water—Continued

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
55	0.7568	0.7563	0.7559	0.7555	0.7551	0.7547	0.7543	0.7539	0.7535	0.7531
56	.7527	.7523	.7519	.7515	.7511	.7507	.7503	.7499	.7495	.7491
57	.7487	.7483	.7479	.7475	.7471	.7467	.7463	.7459	.7455	.7451
58	.7447	.7443	.7439	.7435	.7431	.7427	.7423	.7419	.7415	.7411
59	.7407	.7403	.7400	.7396	.7392	.7388	.7384	.7380	.7376	.7372
60	.7368	.7365	.7361	.7357	.7353	.7349	.7345	.7341	.7338	.7334
61	.7330	.7326	.7322	.7318	.7315	.7311	.7307	.7303	.7299	.7295
62	.7292	.7288	.7284	.7280	.7277	.7273	.7269	.7265	.7261	.7258
63	.7254	.7250	.7246	.7243	.7239	.7235	.7231	.7228	.7224	.7220
64	.7216	.7213	.7209	.7205	.7202	.7198	.7194	.7191	.7187	.7183
65	.7179	.7176	.7172	.7168	.7165	.7161	.7157	.7154	.7150	.7147
66	.7143	.7139	.7136	.7132	.7128	.7125	.7121	.7117	.7114	.7110
67	.7107	.7103	.7099	.7096	.7092	.7089	.7085	.7081	.7078	.7074
68	.7071	.7067	.7064	.7060	.7056	.7053	.7049	.7046	.7042	.7039
69	.7035	.7032	.7028	.7025	.7021	.7018	.7014	.7011	.7007	.7004
70	.7000	.6997	.6993	.6990	.6986	.6983	.6979	.6976	.6972	.6969
71	.6965	.6962	.6958	.6955	.6951	.6948	.6944	.6941	.6938	.6934
72	.6931	.6927	.6924	.6920	.6917	.6914	.6910	.6907	.6903	.6900
73	.6897	.6893	.6890	.6886	.6883	.6880	.6876	.6873	.6869	.6866
74	.6863	.6859	.6856	.6853	.6849	.6846	.6843	.6839	.6836	.6833
75	.6829	.6826	.6823	.6819	.6816	.6813	.6809	.6806	.6803	.6799
76	.6796	.6793	.6790	.6786	.6783	.6780	.6776	.6773	.6770	.6767
77	.6763	.6760	.6757	.6753	.6750	.6747	.6744	.6740	.6737	.6734
78	.6731	.6728	.6724	.6721	.6718	.6715	.6711	.6708	.6705	.6702
79	.6699	.6695	.6692	.6689	.6686	.6683	.6679	.6676	.6673	.6670
80	.6667	.6663	.6660	.6657	.6654	.6651	.6648	.6645	.6641	.6638
81	.6635	.6632	.6629	.6626	.6623	.6619	.6616	.6613	.6610	.6607
82	.6604	.6601	.6598	.6594	.6591	.6588	.6585	.6582	.6579	.6576
83	.6573	.6570	.6567	.6564	.6560	.6557	.6554	.6551	.6548	.6545
84	.6542	.6539	.6536	.6533	.6530	.6527	.6524	.6521	.6518	.6515
85	.6512	.6509	.6506	.6503	.6500	.6497	.6494	.6490	.6487	.6484
86	.6482	.6479	.6476	.6473	.6470	.6467	.6464	.6461	.6458	.6455
87	.6452	.6449	.6446	.6443	.6440	.6437	.6434	.6431	.6428	.6425
88	.6422	.6419	.6416	.6413	.6410	.6407	.6404	.6401	.6399	.6396
89	.6393	.6390	.6387	.6384	.6381	.6378	.6375	.6372	.6369	.6367
90	.6364	.6361	.6358	.6355	.6352	.6349	.6346	.6343	.6341	.6338
91	.6335	.6332	.6329	.6326	.6323	.6321	.6318	.6315	.6312	.6309
92	.6306	.6303	.6301	.6298	.6295	.6292	.6289	.6286	.6284	.6281
93	.6278	.6275	.6272	.6270	.6267	.6264	.6261	.6258	.6256	.6253
94	.6250	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225
95	.6222	.6219	.6217	.6214	.6211	.6208	.6206	.6203	.6200	.6197
96	.6195	.6192	.6189	.6186	.6184	.6181	.6178	.6176	.6173	.6170
97	.6167	.6165	.6162	.6159	.6157	.6154	.6151	.6148	.6146	.6143
98	.6140	.6138	.6135	.6132	.6130	.6127	.6124	.6122	.6119	.6116
99	.6114	.6111	.6108	.6106	.6103	.6100	.6098	.6095	.6092	.6090
100	.6087									

TABLE 23.—Conversion of Density Basis

Prepared for use in reducing readings of a hydrometer graduated to indicate density or specific gravity at a specified standard temperature, T , referred to water at a specified temperature, T' , as unity, to the basis of another standard temperature, t , and reference temperature, t' .

The factor Δ (given in units of the sixth decimal place), multiplied by the density or specific-gravity reading, gives the correction to be applied to the reading to reduce it to the required basis.

Suppose a hydrometer indicates specific gravity at $\frac{20^\circ}{4^\circ}\text{C}$, and it is required to know the correction in order that it shall indicate specific gravity at $\frac{15.56}{15.56}\text{C}$, then,

$$D_{\frac{15.56}{15.56}} = D_{\frac{20}{4}} + \Delta D_{\frac{20}{4}}$$

That is, if the hydrometer indicates correctly a specific gravity of 1.5760 at $\frac{20^\circ}{4^\circ}$, then at $\frac{15.56}{15.56}$ the reading of the instrument will be too low by $1.5760 \times 0.001062 = 0.0017$. A correction of 0.0017 must therefore be added to the indication of the hydrometer.

Or, if a maker using standards indicating $D_{\frac{15.56}{15.56}}\text{C}$ wishes to graduate a hydrometer to indicate density at 20°C referred to water at 4°C ($D_{\frac{20}{4}}$), the readings of the standard must be corrected by use of the factor $+0.001062$.

Suppose the standard reads..... 1.5760

The corresponding correction is $1.6 \times .001062 =$ +0.0017

Corrected reading..... 1.5777

The table is calculated for Jena 16^{mm} glass.

Given Basis of Density	Required Basis of Density $\frac{1}{t'}$									
	$D_{\frac{25^\circ}{4^\circ}\text{C}}$	$D_{\frac{20}{4}}$	$D_{\frac{17.5}{4}}$	$D_{\frac{15.56}{4}}$	$D_{\frac{15}{4}}$	$D_{\frac{15}{15}}$	$D_{\frac{15.56}{15.56}}$	$D_{\frac{17.5}{17.5}}$	$D_{\frac{20}{20}}$	$D_{\frac{25}{25}}$
$\frac{T}{T'}$	Δ (In Units of the Sixth Decimal Place)									
$D_{\frac{25^\circ}{4^\circ}\text{C}}$	0	+ 115	+ 172	+ 217	+ 230	+1104	+1177	+1459	+1884	+2931
$D_{\frac{20}{4}}$	- 115	0	+ 58	+ 102	+ 115	+ 989	+1062	+1345	+1769	+2816
$D_{\frac{17.5}{4}}$	- 172	- 58	0	+ 45	+ 58	+ 932	+1005	+1287	+1711	+2758
$D_{\frac{15.56}{4}}$	- 217	- 102	- 45	0	+ 13	+ 887	+ 960	+1242	+1667	+2713
$D_{\frac{15}{4}}$	- 230	- 115	- 58	- 13	0	+ 874	+ 947	+1229	+1654	+2700
$D_{\frac{15}{15}}$	-1103	- 988	- 931	- 886	- 873	0	+ 73	+ 354	+ 779	+1826
$D_{\frac{15.56}{15.56}}$	-1176	-1061	-1004	- 960	- 947	- 73	0	+ 281	+ 706	+1752
$D_{\frac{17.5}{17.5}}$	-1457	-1343	-1285	-1240	-1227	- 354	- 281	0	+ 424	+1471
$D_{\frac{20}{20}}$	-1881	-1766	-1708	-1664	-1651	- 778	- 705	- 423	0	+1046
$D_{\frac{25}{25}}$	-2923	-2808	-2751	-2707	-2694	-1821	-1748	-1468	-1044	0

TABLE 24.—Weight (in grams), at Various Pressures and Temperatures, of 1 Liter of Dry Air Containing 0.04 Per Cent of CO₂

[Computed from the formula $C = \frac{1.293052}{1 + 0.00367t} \times \frac{h}{760}$, where h is pressure in mm of mercury at 0° C, and standard gravity, and t is temperature in degrees centigrade]

Temperature in Deg. C	Pressure in mm of Hg (0° C, Standard Gravity)											
	720	725	730	735	740	745	750	755	760	765	770	775
15	1.1611	1.1691	1.1772	1.1853	1.1933	1.2014	1.2095	1.2175	1.2256	1.2336	1.2417	1.2498
16	1.1571	1.1651	1.1731	1.1812	1.1892	1.1972	1.2053	1.2133	1.2213	1.2294	1.2374	1.2454
17	1.1531	1.1611	1.1691	1.1771	1.1851	1.1931	1.2011	1.2091	1.2171	1.2251	1.2331	1.2411
18	1.1491	1.1571	1.1650	1.1730	1.1810	1.1890	1.1970	1.2049	1.2129	1.2209	1.2289	1.2369
19	1.1451	1.1531	1.1611	1.1690	1.1770	1.1849	1.1929	1.2008	1.2088	1.2167	1.2247	1.2326
20	1.1412	1.1492	1.1571	1.1650	1.1729	1.1809	1.1888	1.1967	1.2046	1.2126	1.2205	1.2284
21	1.1373	1.1452	1.1531	1.1610	1.1689	1.1768	1.1847	1.1926	1.2005	1.2084	1.2163	1.2242
22	1.1335	1.1414	1.1492	1.1571	1.1650	1.1728	1.1807	1.1886	1.1965	1.2043	1.2122	1.2201
23	1.1296	1.1375	1.1453	1.1532	1.1610	1.1689	1.1767	1.1846	1.1924	1.2002	1.2081	1.2159
24	1.1258	1.1337	1.1415	1.1493	1.1571	1.1649	1.1727	1.1806	1.1884	1.1962	1.2040	1.2118
25	1.1220	1.1298	1.1376	1.1454	1.1532	1.1610	1.1688	1.1766	1.1844	1.1922	1.2000	1.2078
26	1.1183	1.1261	1.1338	1.1416	1.1494	1.1571	1.1649	1.1727	1.1804	1.1882	1.1959	1.2037
27	1.1146	1.1223	1.1300	1.1378	1.1455	1.1533	1.1610	1.1687	1.1765	1.1842	1.1920	1.1997
28	1.1108	1.1186	1.1263	1.1340	1.1417	1.1494	1.1571	1.1648	1.1726	1.1803	1.1880	1.1957
29	1.1072	1.1149	1.1225	1.1302	1.1379	1.1456	1.1533	1.1610	1.1687	1.1764	1.1840	1.1917
30	1.1035	1.1112	1.1188	1.1265	1.1342	1.1418	1.1495	1.1571	1.1648	1.1725	1.1801	1.1878
31	1.0999	1.1075	1.1151	1.1228	1.1304	1.1381	1.1457	1.1533	1.1610	1.1686	1.1762	1.1839

TABLE 25.—Buoyancy Constants (mg/ml)

[Difference in milligrams between the mass and the apparent weight of 1 milliliter of water weighed with brass weights ($d=8.4$) in air at various temperatures and barometer readings (unreduced). A humidity of 50 per cent saturation is assumed. To find the weight of 1 milliliter of air under the conditions assumed in this table, multiply the buoyancy constant by 1.135 (42/37)]

Pressure		Temperature in Degrees Centigrade			
		15	20	25	30
Observed Pressure in Millimeters.	640	0.904	0.886	0.869	0.852
	650	0.918	0.900	0.883	0.866
	660	0.932	0.914	0.897	0.879
	670	0.946	0.928	0.911	0.893
	680	0.960	0.942	0.924	0.906
	690	0.975	0.956	0.938	0.920
	700	0.989	0.970	0.952	0.933
	705	0.996	0.977	0.958	0.940
	710	1.003	0.984	0.965	0.947
	715	1.010	0.991	0.972	0.953
	720	1.017	0.998	0.979	0.960
	725	1.024	1.004	0.985	0.967
	730	1.031	1.011	0.992	0.973
	735	1.038	1.018	0.999	0.980
	740	1.045	1.025	1.006	0.987
	745	1.052	1.032	1.013	0.994
	750	1.059	1.039	1.020	1.000
	755	1.067	1.046	1.027	1.007
	760	1.074	1.053	1.034	1.014
	765	1.081	1.060	1.040	1.020
	770	1.088	1.067	1.047	1.027
	775	1.095	1.074	1.054	1.034
	780	1.102	1.081	1.061	1.041

TABLE 26.—Density (in grams per milliliter) of Water at Temperatures from 0° to 102° C¹

Temp., Deg. C	Density	Temp., Deg. C	Density	Temp., Deg. C	Density
0	0.99987	35	0.99406	70	0.97781
1	.99993	36	.99371	71	.97723
2	.99997	37	.99336	72	.97666
3	.99999	38	.99299	73	.97607
4	1.00000	39	.99262	74	.97548
5	.99999	40	.99224	75	.97489
6	.99997	41	.99186	76	.97428
7	.99993	42	.99147	77	.97368
8	.99988	43	.99107	78	.97307
9	.99981	44	.99066	79	.97245
10	.99973	45	.99024	80	.97183
11	.99963	46	.98982	81	.97120
12	.99952	47	.98940	82	.97057
13	.99940	48	.98896	83	.96994
14	.99927	49	.98852	84	.96930
15	.99913	50	.98807	85	.96865
16	.99897	51	.98762	86	.96800
17	.99880	52	.98715	87	.96734
18	.99862	53	.98669	88	.96668
19	.99843	54	.98621	89	.96601
20	.99823	55	.98573	90	.96534
21	.99802	56	.98524	91	.96467
22	.99780	57	.98478	92	.96399
23	.99756	58	.98425	93	.96330
24	.99732	59	.98375	94	.96261
25	.99707	60	.98324	95	.96192
26	.99681	61	.98272	96	.96122
27	.99654	62	.98220	97	.96051
28	.99626	63	.98167	98	.95981
29	.99597	64	.98113	99	.95909
30	.99567	65	.98059	100	.95838
31	.99537	66	.98005	101	.95765
32	.99505	67	.97950	102	.95693
33	.99473	68	.97894		
34	.99440	69	.97838		
35	.99406	70	.97781		

¹ According to M. Thiesen, *Wiss. Abh. der Physikalisch-Technischen Reichsanstalt*, 4, No. 1; 1904.

TABLE 27.—Density of Pure Water Free from Air

[Under standard pressure (76 cm), at every tenth part of a degree of the international hydrogen scale from 0° to 41° C, in grams per milliliter †]

De- grees Cen- ti- grade	Tenths of Degrees										Mean Differ- ences
	0	1	2	3	4	5	6	7	8	9	
0	0.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59
1	9267	9315	9363	9408	9452	9494	9534	9573	9610	9645	+ 41
2	9679	9711	9741	9769	9796	9821	9844	9866	9887	9905	+ 24
3	9922	9937	9951	9962	9973	9981	9988	9994	9998	*0000	+ 8
4	1.000 0000	*9999	*9996	*9992	*9986	*9979	*9970	*9960	*9947	*9934	- 8
5	0.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	- 24
6	9682	9650	9617	9582	9545	9507	9468	9427	9385	9341	- 39
7	9296	9249	9201	9151	9100	9048	8994	8938	8881	8823	- 53
8	8764	8703	8641	8577	8512	8445	8377	8308	8237	8165	- 67
9	8091	8017	7940	7863	7784	7704	7622	7539	7455	7369	- 81
10	7282	7194	7105	7014	6921	6826	6729	6632	6533	6432	- 95
11	6331	6228	6124	6020	5913	5805	5696	5586	5474	5362	-108
12	5248	5132	5016	4898	4780	4660	4538	4415	4291	4166	-121
13	4040	3912	3784	3654	3523	3391	3257	3122	2986	2850	-133
14	2712	2572	2431	2289	2147	2003	1858	1711	1564	1416	-145
15	1266	1114	0962	0809	0655	0499	0343	0185	0026	*9865	-156
16	0.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	-168
17	8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	-178
18	6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	-190
19	4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	-200
20	2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	-211
21	0233	0016	*9799	*9580	*9359	*9139	*8917	*8694	*8470	*8245	-221
22	0.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	-232
23	5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	-242
24	3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	-252
25	0770	0513	0255	*9997	*9736	*9476	*9214	*8951	*8688	*8423	-261
26	0.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	-271
27	5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	-280
28	2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	-289
29	0.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	-296
30	6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	-307
31	3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	-315
32	0561	0241	*9920	*9599	*9276	*8954	*8630	*8304	*7979	*7653	-324
33	0.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	-332
34	4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	-340
35	0610	0267	*9922	*9576	*9230	*8883	*8534	*8186	*7837	*7486	-347
36	0.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	-355
37	3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	-362
38	0.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	-370
39	6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	-377
40	2497	2116	1734	1352	0971	0587	0203	*9818	*9433	*9047	-384
41	0.991 8661										

† According to P. Chappuis, Bureau International des Poids et Mesures, Travaux et Mémoires, XIII; 1907.

TABLE 28.—Weight of 1 Gallon of Water

[This table is based on the water densities of P. Chappuis (Bureau International des Poids et Mesures, Travaux et Mémoires, XIII; 1907) for 0° to 40° C, and of M. Thiesen (Wiss. Abh. der Physikalisch-Technischen Reichsanstalt, 4, No. 1; 1904) for 41° to 100° C. The weights in air are for dry air at the same temperature as the water up to 40° C and at a (corrected) barometric pressure of 760 mm and against brass weights of 8.4 density at 0° C. Above 40° C the temperature of the air is assumed to be 20° C, i. e., the water is allowed to cool to 20° C before the weighings are made. The volumetric computations are based on the relation that 1 liter=1.000027 cubic decimeters and 1 cubic decimeter=61.023378 cubic inches. The weights corresponding to 154° C (60° F) and 164° C (62° F) have been included in the table because of the frequent use of these temperatures in engineering and industrial work.]

Temperature, °C	Weight in Vacuum		Weight in Air	
	Grams	Pounds	Grams	Pounds
0	3784.833	8.34412	3780.520	8.33461
1	5.055	.34461	0.758	.33613
2	5.211	.34495	0.930	.33551
3	5.303	.34515	1.037	.33575
4	5.332	.34522	1.082	.33585
5	5.302	.34515	1.067	.33582
6	5.212	.34495	0.992	.33565
7	5.066	.34463	0.861	.33536
8	4.864	.34419	0.675	.33495
9	4.610	.34363	0.435	.33442
10	4.303	.34295	0.144	.33378
11	3.943	.34216	3779.798	.33302
12	3.534	.34125	9.403	.33215
13	3.076	.34025	8.960	.33117
14	2.574	.33914	8.472	.33009
15	2.026	.33793	7.939	.32892
(154) 60° F	(3781.703)	(8.33722)	(3777.623)	(8.32823)
16	1.435	.33663	7.362	.32765
(164) 62° F	(3781.017)	(8.33571)	(3776.953)	(8.32675)
17	0.801	.33523	6.741	.32628
18	0.125	.33374	6.080	.32482
19	3779.407	.33216	5.375	.32327
20	8.649	.33049	4.630	.32162
21	7.850	.32872	3.845	.31989
22	7.012	.32688	3.021	.31808
23	6.135	.32494	2.157	.31617
24	5.220	.32293	1.256	.31419
25	4.268	.32083	0.317	.31212
26	3.279	.31865	3769.341	.30996
27	2.254	.31639	8.329	.30773
28	1.195	.31405	7.283	.30543
29	0.100	.31164	6.201	.30304
30	3768.972	.30915	5.086	.30058
31	7.812	.30659	3.938	.29805
32	6.618	.30396	2.757	.29545
33	5.393	.30126	1.545	.29278
34	4.137	.29849	0.301	.29003
35	2.851	.29566	3759.027	.28723
36	1.536	.29276	7.725	.28436
37	0.192	.28979	6.393	.28142
38	3758.820	.28677	5.033	.27842
39	7.420	.28368	3.645	.27536
40	5.995	.28054	2.232	.27225
41	4.52	.2773	0.53	.2685
42	3.04	.2740	3749.05	.2652
43	1.53	.2707	7.54	.2619
44	3749.98	.2673	5.99	.2585

TABLE 28.—Weight of 1 Gallon of Water—Continued

Temperature, °C	Weight in Vacuo		Weight in Air	
	Grams	Pounds	Grams	Pounds
45	3748.39	8.2638	3744.40	8.2550
46	6.80	.2603	2.81	.2515
47	5.21	.2568	1.23	.2480
48	3.54	.2531	3739.56	.2443
49	1.88	.2494	7.90	.2407
50	0.17	.2457	6.20	.2369
51	3738.47	.2419	4.50	.2332
52	6.69	.2380	2.72	.2292
53	4.95	.2341	0.98	.2254
54	3.13	.2301	3729.16	.2214
55	1.32	.2261	7.35	.2174
56	3729.46	.2220	5.50	.2133
57	7.72	.2182	3.76	.2095
58	5.71	.2138	1.75	.2051
59	3.82	.2096	3719.86	.2009
60	1.89	.2054	7.93	.1966
61	3719.92	.2010	5.97	.1923
62	7.95	.1967	4.00	.1880
63	5.95	.1923	2.00	.1835
64	3.90	.1877	3709.95	.1790
65	1.86	.1832	7.91	.1745
66	3709.82	.1787	5.87	.1700
67	7.73	.1741	3.79	.1655
68	5.61	.1695	1.67	.1608
69	3.49	.1648	3699.56	.1561
70	1.33	.1600	7.40	.1514
71	3699.14	.1552	5.21	.1465
72	6.98	.1504	3.05	.1418
73	4.75	.1455	0.82	.1369
74	2.52	.1406	3688.59	.1319
75	0.28	.1357	6.36	.1270
76	3687.97	.1306	4.05	.1219
77	5.70	.1256	1.78	.1169
78	3.39	.1205	3679.48	.1119
79	1.05	.1153	7.13	.1067
80	3678.70	.1101	4.79	.1015
81	6.32	.1049	2.41	.0963
82	3.93	.0996	0.02	.0910
83	1.54	.0944	3667.64	.0858
84	3669.12	.0890	5.22	.0804
85	6.66	.0836	2.76	.0750
86	4.20	.0782	0.31	.0696
87	1.70	.0727	3657.81	.0641
88	3659.21	.0672	5.31	.0586
89	6.67	.0616	2.78	.0530
90	4.13	.0560	0.25	.0474
91	1.60	.0504	3647.71	.0418
92	3649.02	.0447	5.14	.0362
93	6.41	.0390	2.53	.0304
94	3.80	.0332	3639.92	.0247
95	1.19	.0274	7.32	.0189
96	3638.54	.0216	4.67	.0131
97	5.85	.0157	1.98	.0072
98	3.20	.0098	3629.34	.0013
99	0.47	.0038	6.61	7.9953
100	3627.79	7.9979	3.93	.9894

TABLE 29.—Weight of 1 Cubic Foot of Water

[This table is based on the water densities of P. Chappuis (Bureau International des Poids et Mesures, Travaux et Mémoires, XIII; 1907) for 0° to 40° C, and of M. Thiesen (Wis. Abh. der Physikalisch-Technischen Reichsanstalt, 4, No. 1; 1904) for 41° to 100° C. The weights in air are for dry air at the same temperature as the water up to 40° C and at a (corrected) barometric pressure of 760 mm and against brass weights of 8.4 density at 0° C. Above 40° C the temperature of the air is assumed to be 20° C, i. e., the water is allowed to cool to 20° C before the weighings are made. The volumetric computations are based on the relation that 1 liter=1.000027 cubic decimeters and 1 cubic decimeter=61.023378 cubic inches. The weights corresponding to 15½° C (60° F) and 16½° C (62° F) have been included in the table because of the frequent use of these temperatures in engineering and industrial work.]

Temperature, °C	Weight in Vacuo		Weight in Air	
	Grams	Pounds	Grams	Pounds
0	28312.517	62.4183	28280.254	62.3472
1	14.178	.4220	82.033	.3511
2	15.345	.4246	83.321	.3540
3	16.033	.4261	84.121	.3557
4	16.250	.4266	84.458	.3565
5	16.025	.4261	84.345	.3562
6	15.352	.4246	83.784	.3550
7	14.260	.4222	82.804	.3528
8	12.749	.4189	81.413	.3498
9	10.849	.4147	79.618	.3458
10	08.552	.4096	77.441	.3410
11	05.859	.4037	74.853	.3353
12	02.800	.3969	71.898	.3288
13	28299.374	.3894	68.584	.3215
14	95.619	.3811	64.933	.3134
15	91.519	.3720	60.946	.3046
(15½) 60° F	(28289.103)	(62.3667)	(28258.58)	(62.2994)
16	87.098	.3623	56.630	.2951
(16½) 62° F	(28283.971)	(62.3594)	(28253.57)	(62.2884)
17	82.356	.3518	51.985	.2849
18	77.299	.3407	47.040	.2740
19	71.928	.3289	41.766	.2624
20	66.258	.3164	36.193	.2501
21	60.281	.3032	30.321	.2371
22	54.012	.2894	24.157	.2235
23	47.452	.2749	17.694	.2093
24	40.607	.2598	10.954	.1944
25	33.485	.2441	03.930	.1789
26	26.087	.2278	28196.629	.1629
27	18.420	.2109	89.059	.1462
28	10.500	.1934	81.234	.1289
29	02.307	.1754	73.140	.1111
30	28193.869	.1568	64.799	.0927
31	85.191	.1376	56.212	.0737
32	76.259	.1179	47.377	.0543
33	67.096	.0977	38.311	.0343
34	57.700	.0770	29.005	.0138
35	48.080	.0558	19.475	61.9926
36	38.243	.0341	09.735	.9713
37	28.190	.0120	28099.771	.9493
38	17.926	61.9893	89.596	.9269
39	07.454	.9663	79.215	.9040
40	28096.794	.9428	68.645	.8807
41	85.76	.918	55.90	.853
42	74.71	.894	44.86	.828
43	63.39	.869	33.55	.803
44	51.78	.844	21.94	.778

TABLE 29.—Weight of 1 Cubic Foot of Water—Continued

Temperature, °C	Weight in Vacuo		Weight in Air	
	Grams	Pounds	Grams	Pounds
45	28039.88	61.817	28010.06	61.752
46	28.00	.791	27998.19	.725
47	16.10	.765	86.31	.699
48	03.64	.737	73.86	.672
49	27991.18	.710	61.42	.644
50	78.44	.682	48.69	.616
51	65.70	.654	35.96	.588
52	52.39	.624	22.67	.559
53	39.37	.596	09.65	.530
54	25.77	.566	27896.08	.500
55	12.18	.536	82.50	.470
56	27898.31	.505	68.64	.440
57	85.28	.476	55.63	.411
58	70.27	.443	40.63	.378
59	56.12	.412	26.49	.347
60	41.67	.380	12.06	.315
61	26.95	.348	27797.36	.283
62	12.22	.315	82.65	.250
63	27797.21	.282	67.66	.217
64	81.92	.249	52.38	.184
65	66.63	.215	37.11	.150
66	51.34	.181	21.83	.116
67	35.77	.147	06.27	.082
68	19.91	.112	27690.44	.047
69	04.05	.077	74.59	.012
70	27687.92	.041	58.47	60.976
71	71.49	.005	42.07	.940
72	55.35	60.970	25.95	.905
73	38.64	.933	09.25	.868
74	21.94	.896	27592.57	.831
75	05.23	.859	75.88	.794
76	27587.96	.821	58.62	.756
77	70.97	.784	41.65	.719
78	53.69	.745	24.39	.681
79	36.14	.707	06.86	.642
80	18.58	.668	27489.32	.604
81	00.75	.629	71.50	.564
82	27482.90	.589	53.68	.525
83	65.06	.550	35.86	.486
84	46.95	.510	17.76	.446
85	28.54	.470	27399.37	.405
86	10.13	.429	80.99	.365
87	27391.44	.388	62.31	.324
88	72.75	.347	43.65	.282
89	53.78	.305	24.70	.241
90	34.81	.263	05.74	.199
91	15.84	.221	27286.80	.157
92	27296.58	.179	67.56	.115
93	77.05	.136	48.05	.072
94	57.51	.093	28.52	.029
95	37.97	.049	09.01	59.986
96	18.15	.006	27189.20	.942
97	27198.05	59.961	69.13	.898
98	78.22	.918	49.33	.854
99	57.83	.873	28.96	.809
100	37.78	.828	08.87	.765

TABLE 30.—Apparent Weight (in grams) of Water in Air

[This table gives the apparent weight, for temperatures between 15° and 30° C, humidity 50 per cent, uncorrected barometer reading 76 cm of certain volumes of water weighed with brass weights. This table is based on the data given in Tables 25 and 27, and may be conveniently employed to determine definite volumes of water for calibrating instruments. The table assumes the air to be at the same temperature as the water]

Temp. in Degrees C	2000 ml	1000 ml	500 ml	400 ml	300 ml	250 ml	150 ml
15	1996.11	998.05	499.03	399.22	299.42	249.51	149.71
16	1995.80	997.90	498.95	399.16	299.37	249.48	149.68
17	1995.48	997.74	498.87	399.10	299.32	249.43	149.66
18	1995.13	997.56	498.78	399.03	299.27	249.39	149.63
19	1994.76	997.38	498.69	398.95	299.21	249.34	149.61
20	1994.36	997.18	498.59	398.87	299.15	249.30	149.58
21	1993.95	996.97	498.49	398.79	299.09	249.24	149.55
22	1993.51	996.76	498.38	398.70	299.03	249.19	149.51
23	1993.06	996.53	498.26	398.61	298.96	249.13	149.48
24	1992.58	996.29	498.15	398.52	298.89	249.07	149.44
25	1992.09	996.04	498.02	398.42	298.81	249.01	149.41
26	1991.57	995.79	497.89	398.31	298.74	248.95	149.37
27	1991.04	995.52	497.76	398.21	298.66	248.88	149.33
28	1990.49	995.24	497.62	398.10	298.57	248.81	149.29
29	1989.92	994.96	497.48	397.98	298.49	248.74	149.24
30	1989.33	994.66	497.33	397.87	298.40	248.67	149.20

TABLE 31.—Temperature Correction for Glass Volumetric Apparatus

[This table gives the correction to be added to actual capacity (determined at certain temperatures) to give the capacity at the standard temperature, 20° C. Conversely, by subtracting the corrections from the indicated capacity of an instrument standard at 20° C the corresponding capacity at other temperatures is obtained. The table assumes for the cubical coefficient of expansion of glass 0.000025 per degree centigrade. The coefficients of expansion of glasses used for volumetric instruments vary from 0.000023 to 0.000028]

Temp. in Degrees C	2000 ml	1000 ml	500 ml	400 ml	300 ml	250 ml
15	+0.25	+0.12	+0.06	+0.05	+0.04	+0.031
16	+ .20	+ .10	+ .05	+ .04	+ .03	+ .025
17	+ .15	+ .08	+ .04	+ .03	+ .02	+ .019
18	+ .10	+ .05	+ .02	+ .02	+ .02	+ .012
19	+ .05	+ .02	+ .01	+ .01	+ .01	+ .006
21	−0.05	−0.02	−0.01	−0.01	−0.01	−0.006
22	− .10	− .05	− .02	− .02	− .02	− .012
23	− .15	− .08	− .04	− .03	− .02	− .019
24	− .20	− .10	− .05	− .04	− .03	− .025
25	− .25	− .12	− .06	− .05	− .04	− .031
26	−0.30	−0.15	−0.08	−0.06	−0.04	−0.038
27	− .35	− .18	− .09	− .07	− .05	− .044
28	− .40	− .20	− .10	− .08	− .06	− .050
29	− .45	− .22	− .11	− .09	− .07	− .056
30	− .50	− .25	− .12	− .10	− .08	− .062

TABLE 32.—Apparent Weight (in Grams) of Water in Air

[This table gives the apparent weight of certain volumes of water weighed against brass weights in air, humidity 50 per cent, barometer reading 76 cm (unreduced), weighings being made at 20° C, the water and air being at the same temperature. It differs from Table 30 only in its greater temperature range and in the fact that the water is allowed to come to a temperature of 20° C before the weighings are made. The weighings may be made at any temperature between 18° and 22° without introducing errors greater than 1 mg per 100 cc.]

Temp. in De- grees C	2000 ml	1000 ml	500 ml	400 ml	300 ml	250 ml	150 ml
15	1996.14	998.07	499.04	399.23	299.42	249.52	149.71
16	1995.83	997.92	498.96	399.17	299.38	249.48	149.69
17	1995.50	997.75	498.87	399.10	299.32	249.44	149.66
18	1995.14	997.57	498.79	399.03	299.27	249.39	149.64
19	1994.76	997.38	498.69	398.95	299.21	249.35	149.61
20	1994.36	997.18	498.59	398.87	299.15	249.30	149.58
21	1993.94	996.97	498.49	398.79	299.09	249.24	149.55
22	1993.50	996.75	498.37	398.70	299.02	249.19	149.51
23	1993.04	996.52	498.26	398.61	298.96	249.13	149.48
24	1992.55	996.28	498.14	398.51	298.88	249.07	149.44
25	1992.05	996.03	498.01	398.41	298.81	249.01	149.40
26	1991.53	995.76	497.88	398.31	298.73	248.94	149.36
27	1990.99	995.49	497.75	398.20	298.65	248.87	149.32
28	1990.43	995.21	497.61	398.09	298.56	248.80	149.28
29	1989.85	994.93	497.46	397.97	298.48	248.73	149.24
30	1989.26	994.63	497.31	397.85	298.39	248.66	149.19
35	1986.02	993.01	496.51	397.20	297.90	248.25	148.95
40	1982.41	991.20	495.60	396.48	297.36	247.80	148.68
45	1978.4	989.2	494.6	395.7	296.8	247.3	148.4
50	1974.1	987.0	493.5	394.8	296.1	246.8	148.1
55	1969.4	984.7	492.3	393.9	295.4	246.2	147.7
60	1964.4	982.2	491.1	392.9	294.7	245.6	147.3
65	1959.1	979.6	489.8	391.8	293.9	244.9	146.9
70	1953.6	976.8	488.4	390.7	293.0	244.2	146.5
75	1947.7	973.9	486.9	389.5	292.2	243.5	146.1
80	1941.6	970.8	485.4	388.3	291.2	242.7	145.6
85	1935.3	967.6	483.8	387.1	290.3	241.9	145.1
90	1928.6	964.3	482.2	385.7	289.3	241.1	144.6
95	1921.8	960.9	480.5	384.4	288.3	240.2	144.1
100	1914.7	957.4	478.7	382.9	287.2	239.3	143.6

TABLE 33.—Temperature Correction for Volumetric Solutions

[This table gives the correction to various observed volumes of water, measured at the designated temperatures, to give the volume at the standard temperature, 20° C. Conversely, by subtracting the corrections from the volume desired at 20° C, the volume that must be measured out at the designated temperatures in order to give the desired volume at 20° C, will be obtained. It is assumed that the volumes are measured in glass apparatus having a coefficient of cubical expansion of 0.000025 per degree centigrade. The table is applicable to dilute aqueous solutions having the same coefficient of expansion as water]

Temp. of measurement, °C	Capacity of apparatus in milliliters at 20° C						
	2000	1000	500	400	300	250	150
	Correction in milliliters to give volume of water at 20° C						
15	+1.54	+0.77	+0.38	+0.31	+0.23	+0.19	+0.12
16	+1.28	+0.64	+0.32	+0.26	+0.19	+0.16	+0.10
17	+0.99	+0.50	+0.25	+0.20	+0.15	+0.12	+0.07
18	+0.68	+0.34	+0.17	+0.14	+0.10	+0.08	+0.05
19	+0.35	+0.18	+0.09	+0.07	+0.05	+0.04	+0.03
21	-0.37	-0.18	-0.09	-0.07	-0.06	-0.05	-0.03
22	-0.77	-0.38	-0.19	-0.15	-0.12	-0.10	-0.06
23	-1.18	-0.59	-0.30	-0.24	-0.18	-0.15	-0.09
24	-1.61	-0.81	-0.40	-0.32	-0.24	-0.20	-0.12
25	-2.07	-1.03	-0.52	-0.41	-0.31	-0.26	-0.15
26	-2.54	-1.27	-0.64	-0.51	-0.38	-0.32	-0.19
27	-3.03	-1.52	-0.76	-0.61	-0.46	-0.38	-0.23
28	-3.55	-1.77	-0.89	-0.71	-0.53	-0.44	-0.27
29	-4.08	-2.04	-1.02	-0.82	-0.61	-0.51	-0.31
30	-4.62	-2.31	-1.16	-0.92	-0.69	-0.58	-0.35

In using the above table to correct the volume of certain standard solutions to 20° C more accurate results will be obtained if the numerical values of the corrections are increased by the percentages given below:

Solution	Normality		
	N	N/2	N/10
HNO ₃	50	25	6
H ₂ SO ₄	45	25	5
Na OH	40	25	5
KOH	40	20	4

The weight of a body in vacuo is determined by adding to its apparent weight in air a buoyancy correction equal to the weight of the air displaced by the difference in volume of the body weighed and the weights required to balance it on an equal arm balance.

$$M = W + \rho \left(\frac{M}{d_1} - \frac{W}{d_2} \right) = W \frac{d_1}{d_2} \left(\frac{d_2 - \rho}{d_1 - \rho} \right) = W \frac{d_1}{d_1 - \rho} \left(1 - \frac{\rho}{d_2} \right) =$$

$$W \left[1 + \frac{\rho}{d_2} \left(\frac{d_2 - d_1}{d_1 - \rho} \right) \right] = W + kW/1000$$

M = weight in vacuo; W = apparent weight in air; ρ = density of air; d_1 = density of body; d_2 = density of weights.

The following table has been computed for $\rho = 0.0012$:

TABLE 34.—Reduction of Weighings to Vacuo

Density of Body Weighed, g/cm ³	Correction Factor, k			Density of Body Weighed, g/cm ³	Correction Factor, k		
	Pt. Ir. Weights d=21.5g/cm ³	Brass Weights 8.4	Quartz or Al. Wts. 2.65		Pt. Ir. Weights d=21.5g/cm ³	Brass Weights 8.4	Quartz or Al. Wts. 2.65
0.5	+2.35	+2.26	+1.95	5.0	+0.18	+0.10	-0.21
.6	+1.95	+1.86	+1.55	6.0	+ .15	+ .06	- .25
.7	+1.66	+1.57	+1.26	7.0	+ .12	+ .03	- .28
.8	+1.45	+1.36	+1.05	8.0	+ .10	+ .01	- .30
.9	+1.28	+1.19	+ .88	9.0	+ .08	- .01	- .32
1.0	+1.14	+1.06	+ .75	10.0	+ .06	- .02	- .33
1.1	+1.04	+ .95	+ .64	11.0	+ .05	- .03	- .34
1.2	+ .94	+ .86	+ .55	12.0	+ .04	- .04	- .35
1.3	+ .87	+ .78	+ .47	13.0	+ .04	- .05	- .36
1.4	+ .80	+ .72	+ .40	14.0	+ .03	- .06	- .37
1.5	+ .74	+ .66	+ .35	15.0	+ .02	- .06	- .37
1.6	+ .69	+ .61	+ .30	16.0	+ .02	- .07	- .38
1.7	+ .65	+ .56	+ .25	17.0	+ .01	- .07	- .38
1.8	+ .61	+ .52	+ .21	18.0	+ .01	- .08	- .39
1.9	+ .58	+ .49	+ .18	19.0	+ .01	- .08	- .39
2.0	+ .54	+ .46	+ .15	20.0	.00	- .08	- .39
2.5	+ .42	+ .34	+ .03	21.0	.00	- .09	- .40
3.0	+ .34	+ .26	- .05	22.0	.00	- .09	- .40
3.5	+ .29	+ .20	- .11	23.0	.00	- .09	- .40
4.0	+ .24	+ .16	- .15	24.0	- .01	- .09	- .40

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR

Tables 35 to 47 are intended for the calculation of capacities of glass vessels of common sizes from the weight (in air) of the water contained or delivered. They give for each nominal capacity and observed temperature the amounts to be added to the apparent weight (in air against brass weights) of the water contained in or delivered by a glass vessel to give the capacity in milliliters at 20° C. They are calculated on the following data assumed as approximating ordinary conditions:

Observed barometric pressure.....	76 cm
Relative humidity.....	50 per cent
Coefficient of expansion of glass.....	0.000025 per deg. C

EXAMPLE OF USE OF TABLE.

Determination of capacity of glass measuring flask marked "To contain 250 ml at 20° C."

Apparent weight of water at the observed temperature 22°3 C.....	249.198g
From Table 35, correction.....	0.813

Actual capacity at 20°..... 250.011 ml

TABLE 35.—Indicated Capacity 250 ml

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C]

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.518	0.521	0.524	0.528	0.530	0.534	0.537	0.540	0.543	0.546
16	.550	.554	.556	.560	.563	.567	.570	.574	.578	.581
17	.584	.588	.592	.596	.599	.603	.606	.610	.614	.618
18	.622	.626	.630	.633	.638	.642	.646	.649	.654	.658
19	.662	.666	.670	.674	.679	.683	.687	.692	.696	.700
20	.705	.709	.714	.718	.722	.727	.732	.736	.741	.746
21	.750	.754	.760	.764	.769	.774	.778	.784	.788	.793
22	.798	.804	.808	.813	.818	.824	.828	.834	.839	.844
23	.849	.854	.860	.865	.870	.875	.881	.886	.892	.897
24	.902	.908	.913	.919	.924	.930	.936	.941	.947	.952
25	.958	.964	.969	.975	.981	.986	.993	.998	1.004	1.010
26	1.016	1.022	1.028	1.034	1.040	1.046	1.052	1.058	1.064	1.070
27	1.076	1.082	1.089	1.095	1.101	1.108	1.114	1.120	1.126	1.132
28	1.139	1.146	1.152	1.158	1.165	1.172	1.178	1.184	1.191	1.198
29	1.204	1.211	1.218							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C

TABLE 36.—Indicated Capacity 200 ml

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.414	0.417	0.419	0.422	0.424	0.427	0.430	0.432	0.435	0.437
16	.440	.443	.445	.448	.451	.454	.456	.459	.462	.465
17	.468	.470	.473	.477	.479	.482	.485	.488	.491	.494
18	.497	.501	.504	.507	.510	.513	.516	.519	.523	.526
19	.529	.533	.536	.540	.543	.546	.550	.553	.557	.560
20	.564	.567	.571	.574	.578	.582	.585	.589	.593	.596
21	.600	.604	.608	.612	.615	.619	.623	.627	.631	.635
22	.639	.643	.647	.650	.655	.659	.663	.667	.671	.675
23	.679	.683	.688	.692	.696	.700	.705	.709	.713	.717
24	.722	.726	.731	.735	.739	.744	.748	.753	.757	.762
25	.766	.771	.775	.780	.785	.789	.794	.799	.803	.808
26	.813	.818	.822	.827	.832	.837	.842	.846	.851	.856
27	.861	.866	.871	.876	.881	.886	.891	.896	.901	.906
28	.911	.917	.922	.927	.932	.937	.942	.947	.953	.958
29	.963	.969	.974							

TABLE 37.—Indicated Capacity 150 ml

15	0.311	0.313	0.314	0.316	0.318	0.320	0.322	0.324	0.326	0.328
16	.330	.332	.334	.336	.338	.340	.342	.344	.346	.349
17	.351	.353	.355	.357	.359	.362	.364	.366	.368	.371
18	.373	.375	.378	.380	.383	.385	.387	.390	.392	.395
19	.397	.400	.402	.405	.408	.410	.412	.415	.418	.420
20	.423	.425	.428	.431	.433	.436	.439	.442	.445	.448
21	.450	.453	.456	.459	.461	.464	.467	.470	.473	.476
22	.479	.483	.485	.488	.491	.494	.497	.500	.503	.506
23	.509	.512	.516	.519	.522	.525	.529	.532	.535	.538
24	.541	.545	.548	.551	.554	.558	.562	.565	.568	.571
25	.575	.578	.581	.585	.588	.592	.596	.599	.602	.606
26	.610	.613	.617	.620	.624	.628	.631	.635	.638	.642
27	.645	.649	.653	.657	.661	.664	.668	.672	.676	.680
28	.684	.688	.691	.695	.699	.703	.707	.711	.715	.719
29	.722	.726	.730							

TABLE 38.—Indicated Capacity 100 ml

15	0.207	0.208	0.210	0.211	0.212	0.213	0.215	0.216	0.217	0.219
16	.220	.221	.223	.224	.225	.227	.228	.230	.231	.232
17	.234	.235	.237	.238	.240	.241	.243	.244	.246	.247
18	.249	.250	.252	.253	.255	.257	.258	.260	.261	.263
19	.265	.266	.268	.270	.272	.273	.275	.277	.278	.280
20	.282	.284	.285	.287	.289	.291	.293	.294	.296	.298
21	.300	.302	.304	.306	.308	.310	.311	.314	.315	.317
22	.319	.321	.323	.325	.327	.329	.331	.333	.336	.338
23	.340	.342	.344	.346	.348	.350	.352	.354	.357	.359
24	.361	.363	.365	.368	.370	.372	.374	.376	.379	.381
25	.383	.386	.388	.390	.392	.395	.397	.399	.402	.404
26	.406	.409	.411	.414	.416	.418	.421	.423	.426	.428
27	.431	.433	.436	.438	.440	.443	.446	.448	.451	.453
28	.456	.458	.461	.463	.466	.469	.471	.474	.476	.479
29	.482	.484	.487							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C]

TABLE 39.—Indicated Capacity 90 ml

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.186	0.188	0.189	0.190	0.191	0.192	0.193	0.194	0.196	0.197
16	.198	.199	.200	.202	.203	.204	.205	.207	.208	.209
17	.210	.212	.213	.214	.216	.217	.218	.220	.221	.222
18	.224	.225	.227	.228	.230	.231	.232	.234	.235	.237
19	.238	.240	.241	.243	.244	.246	.247	.249	.251	.252
20	.254	.255	.257	.258	.260	.262	.263	.265	.267	.268
21	.270	.272	.273	.275	.277	.278	.280	.282	.284	.286
22	.287	.289	.291	.293	.295	.296	.298	.300	.302	.304
23	.306	.308	.309	.311	.313	.315	.317	.319	.321	.323
24	.325	.327	.329	.331	.333	.335	.337	.339	.341	.343
25	.345	.347	.349	.351	.353	.355	.357	.359	.362	.364
26	.366	.368	.370	.372	.374	.377	.379	.381	.383	.385
27	.388	.390	.392	.394	.396	.399	.401	.403	.406	.408
28	.410	.412	.415	.417	.419	.422	.424	.426	.429	.431
29	.434	.436	.438							

TABLE 40.—Indicated Capacity 80 ml

15	0.166	0.167	0.168	0.169	0.170	0.171	0.172	0.173	0.174	0.175
16	.176	.177	.178	.179	.180	.181	.183	.184	.185	.186
17	.187	.188	.189	.191	.192	.193	.194	.195	.196	.198
18	.199	.200	.201	.203	.204	.205	.206	.208	.209	.210
19	.212	.213	.214	.216	.217	.218	.220	.221	.223	.224
20	.226	.227	.228	.230	.231	.233	.234	.236	.237	.239
21	.240	.241	.243	.245	.246	.248	.249	.251	.252	.254
22	.255	.257	.259	.260	.262	.264	.265	.267	.268	.270
23	.272	.273	.275	.277	.278	.280	.282	.284	.285	.287
24	.289	.290	.292	.294	.296	.298	.299	.301	.303	.305
25	.306	.308	.310	.312	.314	.316	.318	.320	.321	.323
26	.325	.327	.329	.331	.333	.335	.337	.339	.341	.342
27	.344	.346	.348	.350	.352	.354	.356	.358	.360	.362
28	.365	.367	.369	.371	.373	.375	.377	.379	.381	.383
29	.385	.387	.390							

TABLE 41.—Indicated Capacity 70 ml

15	0.145	0.146	0.147	0.148	0.148	0.149	0.150	0.151	0.152	0.153
16	.154	.155	.156	.157	.158	.159	.160	.161	.162	.163
17	.164	.165	.166	.167	.168	.169	.170	.171	.172	.173
18	.174	.175	.176	.177	.178	.180	.181	.182	.183	.184
19	.185	.186	.188	.189	.190	.191	.192	.194	.195	.196
20	.197	.199	.200	.201	.202	.204	.205	.206	.207	.209
21	.210	.211	.213	.214	.216	.217	.218	.220	.221	.222
22	.224	.225	.226	.228	.229	.230	.232	.233	.235	.236
23	.238	.239	.241	.242	.244	.245	.247	.248	.250	.251
24	.253	.254	.256	.257	.259	.260	.262	.263	.265	.267
25	.268	.270	.271	.273	.274	.276	.278	.280	.281	.283
26	.284	.286	.288	.289	.291	.293	.294	.296	.298	.299
27	.301	.303	.305	.307	.308	.310	.312	.314	.315	.317
28	.319	.321	.323	.324	.326	.328	.330	.332	.333	.335
29	.337	.339	.341							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C]

TABLE 42.—Indicated Capacity 60 ml

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.124	0.125	0.126	0.127	0.127	0.128	0.129	0.130	0.130	0.131
16	.132	.133	.134	.134	.135	.136	.137	.138	.139	.140
17	.140	.141	.142	.143	.144	.145	.145	.147	.147	.148
18	.150	.150	.151	.152	.153	.154	.155	.156	.157	.158
19	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
20	.169	.170	.171	.172	.173	.175	.176	.177	.178	.179
21	.180	.181	.182	.183	.185	.186	.187	.188	.189	.190
22	.192	.193	.194	.195	.196	.198	.199	.200	.201	.202
23	.204	.205	.206	.208	.209	.210	.211	.213	.214	.215
24	.216	.218	.219	.220	.222	.223	.225	.226	.227	.228
25	.230	.231	.232	.234	.235	.237	.238	.240	.241	.242
26	.244	.245	.247	.248	.250	.251	.253	.254	.255	.257
27	.258	.260	.261	.263	.264	.266	.267	.269	.270	.272
28	.273	.275	.276	.278	.280	.281	.283	.284	.286	.288
29	.289	.291	.292							

TABLE 43.—Indicated Capacity 50 ml

15	0.104	0.104	0.105	0.106	0.106	0.107	0.107	0.108	0.109	0.109
16	.110	.111	.111	.112	.113	.113	.114	.115	.116	.116
17	.117	.118	.118	.119	.120	.121	.121	.122	.123	.124
18	.124	.125	.126	.127	.128	.128	.129	.130	.131	.132
19	.132	.133	.134	.135	.136	.137	.137	.138	.139	.140
20	.141	.142	.143	.144	.144	.145	.146	.147	.148	.149
21	.150	.151	.152	.153	.154	.155	.156	.157	.158	.159
22	.160	.161	.162	.163	.164	.165	.166	.167	.168	.169
23	.170	.171	.172	.173	.174	.175	.176	.177	.178	.179
24	.180	.182	.183	.184	.185	.186	.187	.188	.189	.190
25	.192	.193	.194	.195	.196	.197	.199	.200	.201	.202
26	.203	.204	.206	.207	.208	.209	.210	.212	.213	.214
27	.215	.216	.218	.219	.220	.222	.223	.224	.225	.226
28	.228	.229	.230	.232	.233	.234	.236	.237	.238	.240
29	.241	.242	.244							

TABLE 44.—Indicated Capacity 45 ml

15	0.093	0.094	0.094	0.095	0.095	0.096	0.097	0.097	0.098	0.098
16	.099	.100	.100	.101	.101	.102	.103	.103	.104	.105
17	.105	.106	.107	.107	.108	.108	.109	.110	.111	.111
18	.112	.113	.113	.114	.115	.115	.116	.117	.118	.118
19	.119	.120	.121	.121	.122	.123	.124	.124	.125	.126
20	.127	.128	.128	.129	.130	.131	.132	.132	.133	.134
21	.135	.136	.137	.138	.138	.139	.140	.141	.142	.143
22	.144	.145	.145	.146	.147	.148	.149	.150	.151	.152
23	.153	.154	.155	.156	.157	.158	.159	.160	.160	.161
24	.162	.163	.164	.165	.166	.167	.168	.169	.170	.171
25	.172	.173	.174	.176	.177	.178	.179	.180	.181	.182
26	.183	.184	.185	.186	.187	.188	.189	.190	.192	.193
27	.194	.195	.196	.197	.198	.199	.201	.202	.203	.204
28	.205	.206	.207	.209	.210	.211	.212	.213	.214	.216
29	.217	.218	.219							

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS
VESSELS FROM THE WEIGHT OF WATER IN AIR—Continued**

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C]

TABLE 45.—Indicated Capacity 40 ml

Temp. in Deg. C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.083	0.083	0.084	0.084	0.085	0.085	0.086	0.086	0.087	0.087
16	.088	.089	.089	.090	.090	.091	.091	.092	.092	.093
17	.094	.094	.095	.095	.096	.096	.097	.098	.098	.099
18	.099	.100	.101	.101	.102	.102	.103	.104	.105	.105
19	.106	.107	.107	.108	.109	.109	.110	.111	.111	.112
20	.113	.113	.114	.115	.116	.116	.117	.118	.119	.119
21	.120	.121	.122	.122	.123	.124	.125	.125	.126	.127
22	.128	.129	.129	.130	.131	.132	.133	.133	.134	.135
23	.136	.137	.138	.138	.139	.140	.141	.142	.143	.143
24	.144	.145	.146	.147	.148	.149	.150	.151	.151	.152
25	.153	.154	.155	.156	.157	.158	.159	.160	.161	.162
26	.163	.164	.164	.165	.166	.167	.168	.169	.170	.171
27	.172	.173	.174	.175	.176	.177	.178	.179	.180	.181
28	.182	.183	.184	.185	.186	.187	.188	.189	.191	.192
29	.193	.194	.195							

TABLE 46.—Indicated Capacity 35 ml

15	0.073	0.073	0.073	0.074	0.074	0.075	0.075	0.076	0.076	0.076
16	.077	.078	.078	.078	.079	.079	.080	.080	.081	.081
17	.082	.082	.083	.083	.084	.084	.085	.085	.086	.086
18	.087	.088	.088	.089	.089	.090	.090	.091	.091	.092
19	.092	.093	.094	.094	.095	.096	.096	.097	.097	.098
20	.099	.099	.100	.100	.101	.102	.102	.103	.104	.104
21	.105	.106	.106	.107	.108	.108	.109	.110	.110	.111
22	.112	.113	.113	.114	.115	.115	.116	.117	.117	.118
23	.119	.120	.120	.121	.122	.122	.123	.124	.125	.126
24	.126	.127	.128	.129	.129	.130	.131	.132	.133	.133
25	.134	.135	.136	.137	.137	.138	.139	.140	.141	.141
26	.142	.143	.144	.145	.146	.146	.147	.148	.149	.150
27	.151	.152	.152	.153	.154	.155	.156	.157	.158	.159
28	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
29	.169	.170	.170							

TABLE 47.—Indicated Capacity 30 ml

15	0.062	0.063	0.063	0.063	0.064	0.064	0.064	0.065	0.065	0.066
16	.066	.066	.067	.067	.068	.068	.068	.069	.069	.070
17	.070	.071	.071	.071	.072	.072	.073	.073	.074	.074
18	.075	.075	.076	.076	.077	.077	.077	.078	.078	.079
19	.079	.080	.080	.081	.081	.082	.082	.083	.084	.084
20	.085	.085	.086	.086	.087	.087	.088	.088	.089	.089
21	.090	.091	.091	.092	.092	.093	.093	.094	.094	.095
22	.096	.096	.097	.098	.098	.099	.099	.100	.101	.101
23	.102	.103	.103	.104	.104	.105	.106	.106	.107	.108
24	.108	.109	.110	.110	.111	.112	.112	.113	.114	.114
25	.115	.116	.116	.117	.118	.118	.119	.120	.121	.121
26	.122	.123	.123	.124	.125	.126	.126	.127	.128	.128
27	.129	.130	.131	.131	.132	.133	.134	.134	.135	.136
28	.137	.137	.138	.139	.140	.141	.141	.142	.143	.144
29	.145	.145	.146							

MASTER SCALES FOR THE GRADUATION OF HYDROMETERS

The accompanying tables were prepared for the use of hydrometer makers in the graduation of hydrometer scales to indicate percentages of ethyl alcohol by weight at 20° C or by volume at 60° F, and they give the proportional length of any part of the hydrometer scale, assuming that the entire scale has a length of 1000 mm^a and that the hydrometer stem is of uniform cross section. For example, if it is required to construct a hydrometer scale having a certain range the spacing of the graduations of the scale should be made proportional to the differences of the lengths shown in the table for that range.

These tables were prepared from the alcoholometric tables published in this circular, (Tables 2 and 3). The original work on which the tables are based is described in detail in the Bulletin of the Bureau of Standards, Vol. 9, p. 328 (Reprint No. 197). The indications of hydrometers graduated in accordance with these master scales will be on the basis officially adopted by the Bureau of Standards. Hydrometers may also be graduated to indicate percentages of "proof spirit," according to the official tables of the United States Bureau of Internal Revenue (adopted 1913), by the use of the accompanying master scale intended for the graduation of hydrometers to indicate percentages of alcohol by volume at 60° F. The percentage of proof spirit is in every case twice the percentage of alcohol by volume. For example, 25 per cent alcohol by volume is equivalent to 50 per cent proof spirit; 50 per cent alcohol by volume is equivalent to 100 per cent proof spirit. The spacing of the graduations for proof spirit hydrometers can therefore be taken directly from Table 49, the per cent alcohol by volume being multiplied by 2 in each case to give the equivalent per cent proof spirit.

^aAny other convenient unit may be employed; the tabulated lengths will then be in that unit.

TABLE 48.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C

[Total length of scale 1000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
0.0	0.00	5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45
.1	0.71	.1	34.40	.1	63.51	.1	90.00	.1	115.99
.2	1.42	.2	35.02	.2	64.06	.2	90.50	.2	116.53
.3	2.13	.3	35.64	.3	64.61	.3	91.00	.3	117.07
.4	2.84	.4	36.26	.4	65.16	.4	91.50	.4	117.61
.5	3.55	.5	36.87	.5	65.71	.5	91.99	.5	118.15
.6	4.26	.6	37.48	.6	66.26	.6	92.48	.6	118.69
.7	4.97	.7	38.08	.7	66.81	.7	92.98	.7	119.23
.8	5.68	.8	38.68	.8	67.36	.8	93.48	.8	119.78
.9	6.38	.9	39.28	.9	67.91	.9	93.98	.9	120.33
1.0	7.08	6.0	39.88	11.0	68.45	16.0	94.49	21.0	120.88
.1	7.78	.1	40.48	.1	68.99	.1	95.00	.1	121.43
.2	8.48	.2	41.08	.2	69.53	.2	95.51	.2	121.98
.3	9.18	.3	41.68	.3	70.07	.3	96.02	.3	122.53
.4	9.88	.4	42.28	.4	70.61	.4	96.53	.4	123.08
.5	10.58	.5	42.88	.5	71.15	.5	97.04	.5	123.63
.6	11.28	.6	43.47	.6	71.69	.6	97.55	.6	124.18
.7	11.97	.7	44.06	.7	72.23	.7	98.06	.7	124.73
.8	12.66	.8	44.65	.8	72.77	.8	98.57	.8	125.28
.9	13.35	.9	45.24	.9	73.31	.9	99.08	.9	125.83
2.0	14.04	7.0	45.82	12.0	73.84	17.0	99.60	22.0	126.38
.1	14.73	.1	46.40	.1	74.37	.1	100.12	.1	126.94
.2	15.42	.2	46.98	.2	74.90	.2	100.64	.2	127.50
.3	16.11	.3	47.56	.3	75.43	.3	101.16	.3	128.06
.4	16.80	.4	48.14	.4	75.96	.4	101.68	.4	128.62
.5	17.49	.5	48.72	.5	76.49	.5	102.20	.5	129.19
.6	18.18	.6	49.30	.6	77.02	.6	102.72	.6	129.76
.7	18.87	.7	49.88	.7	77.55	.7	103.24	.7	130.32
.8	19.55	.8	50.46	.8	78.08	.8	103.76	.8	130.90
.9	20.22	.9	51.04	.9	78.61	.9	104.28	.9	131.47
3.0	20.89	8.0	51.62	13.0	79.13	18.0	104.80	23.0	132.04
.1	21.56	.1	52.19	.1	79.65	.1	105.32	.1	132.61
.2	22.22	.2	52.76	.2	80.17	.2	105.85	.2	133.18
.3	22.88	.3	53.33	.3	80.69	.3	106.38	.3	133.75
.4	23.54	.4	53.90	.4	81.21	.4	106.91	.4	134.32
.5	24.20	.5	54.47	.5	81.73	.5	107.44	.5	134.89
.6	24.85	.6	55.04	.6	82.25	.6	107.97	.6	135.46
.7	25.50	.7	55.61	.7	82.77	.7	108.50	.7	136.03
.8	26.15	.8	56.18	.8	83.29	.8	109.03	.8	136.60
.9	26.80	.9	56.75	.9	83.81	.9	109.56	.9	137.18
4.0	27.45	9.0	57.32	14.0	84.33	19.0	110.09	24.0	137.76
.1	28.09	.1	57.89	.1	84.85	.1	110.62	.1	138.34
.2	28.73	.2	58.46	.2	85.37	.2	111.15	.2	138.92
.3	29.37	.3	59.03	.3	85.89	.3	111.68	.3	139.50
.4	30.01	.4	59.60	.4	86.41	.4	112.21	.4	140.09
.5	30.64	.5	60.17	.5	86.93	.5	112.75	.5	140.68
.6	31.27	.6	60.73	.6	87.45	.6	113.29	.6	141.27
.7	31.90	.7	61.29	.7	87.97	.7	113.83	.7	141.86
.8	32.53	.8	61.85	.8	88.49	.8	114.37	.8	142.45
.9	33.16	.9	62.41	.9	89.00	.9	114.91	.9	143.04
5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45	25.0	143.63

TABLE 48.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	143.63	30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41
.1	144.22	.1	176.63	.1	213.88	.1	255.62	.1	301.85
.2	144.82	.2	177.33	.2	214.67	.2	256.50	.2	302.29
.3	145.42	.3	178.03	.3	215.46	.3	257.38	.3	303.23
.4	146.02	.4	178.73	.4	216.26	.4	258.26	.4	304.17
.5	146.62	.5	179.43	.5	217.06	.5	259.14	.5	305.12
.6	147.23	.6	180.13	.6	217.86	.6	260.02	.6	306.07
.7	147.84	.7	180.84	.7	218.66	.7	260.90	.7	307.02
.8	148.45	.8	181.55	.8	219.46	.8	261.79	.8	307.97
.9	149.06	.9	182.26	.9	220.26	.9	262.68	.9	308.92
26.0	149.67	31.0	182.97	36.0	221.06	41.0	263.57	46.0	309.88
.1	150.28	.1	183.68	.1	221.86	.1	264.46	.1	310.84
.2	150.90	.2	184.40	.2	222.67	.2	265.35	.2	311.80
.3	151.52	.3	185.12	.3	223.48	.3	266.24	.3	312.76
.4	152.14	.4	185.85	.4	224.29	.4	267.14	.4	313.72
.5	152.77	.5	186.58	.5	225.10	.5	268.04	.5	314.68
.6	153.40	.6	187.31	.6	225.91	.6	268.94	.6	315.64
.7	154.03	.7	188.04	.7	226.73	.7	269.84	.7	316.60
.8	154.66	.8	188.77	.8	227.55	.8	270.74	.8	317.56
.9	155.29	.9	189.51	.9	228.37	.9	271.64	.9	318.52
27.0	155.93	32.0	190.25	37.0	229.19	42.0	272.55	47.0	319.49
.1	156.57	.1	190.99	.1	230.01	.1	273.46	.1	320.46
.2	157.21	.2	191.73	.2	230.84	.2	274.37	.2	321.43
.3	157.85	.3	192.47	.3	231.67	.3	275.28	.3	322.40
.4	158.49	.4	193.21	.4	232.50	.4	276.19	.4	323.37
.5	159.14	.5	193.95	.5	233.34	.5	277.11	.5	324.34
.6	159.79	.6	194.69	.6	234.18	.6	278.03	.6	325.31
.7	160.44	.7	195.44	.7	235.02	.7	278.95	.7	326.28
.8	161.09	.8	196.19	.8	235.86	.8	279.87	.8	327.25
.9	161.74	.9	196.94	.9	236.70	.9	280.79	.9	328.22
28.0	162.40	33.0	197.69	38.0	237.54	43.0	281.71	48.0	329.19
.1	163.06	.1	198.45	.1	238.38	.1	282.63	.1	330.16
.2	163.72	.2	199.21	.2	239.23	.2	283.55	.2	331.14
.3	164.38	.3	199.97	.3	240.08	.3	284.48	.3	332.12
.4	165.04	.4	200.73	.4	240.93	.4	285.41	.4	333.10
.5	165.70	.5	201.49	.5	241.78	.5	286.34	.5	334.09
.6	166.37	.6	202.25	.6	242.63	.6	287.27	.6	335.08
.7	167.04	.7	203.01	.7	243.49	.7	288.20	.7	336.07
.8	167.71	.8	203.77	.8	244.35	.8	289.13	.8	337.06
.9	168.38	.9	204.53	.9	245.21	.9	290.07	.9	338.05
29.0	169.06	34.0	205.30	39.0	246.07	44.0	291.01	49.0	339.04
.1	169.74	.1	206.07	.1	246.93	.1	291.95	.1	340.03
.2	170.42	.2	206.84	.2	247.79	.2	292.89	.2	341.02
.3	171.10	.3	207.61	.3	248.65	.3	293.83	.3	342.01
.4	171.78	.4	208.38	.4	249.51	.4	294.77	.4	343.00
.5	172.47	.5	209.16	.5	250.38	.5	295.71	.5	343.99
.6	173.16	.6	209.94	.6	251.25	.6	296.65	.6	344.98
.7	173.85	.7	210.72	.7	252.12	.7	297.59	.7	345.97
.8	174.54	.8	211.51	.8	252.99	.8	298.53	.8	346.96
.9	175.23	.9	212.30	.9	253.86	.9	299.47	.9	347.96
30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41	50.0	348.96

TABLE 48.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
50.0	348.96	55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65
.1	349.96	.1	401.46	.1	455.21	.1	511.34	.1	569.85
.2	350.96	.2	402.52	.2	456.31	.2	512.49	.2	571.05
.3	351.96	.3	403.58	.3	457.41	.3	513.64	.3	572.25
.4	352.96	.4	404.64	.4	458.51	.4	514.79	.4	573.45
.5	353.97	.5	405.70	.5	459.61	.5	515.94	.5	574.65
.6	354.98	.6	406.76	.6	460.71	.6	517.09	.6	575.85
.7	355.99	.7	407.82	.7	461.82	.7	518.24	.7	577.05
.8	357.01	.8	408.88	.8	462.93	.8	519.39	.8	578.25
.9	358.03	.9	409.94	.9	464.04	.9	520.54	.9	579.46
51.0	359.05	56.0	411.00	61.0	465.15	66.0	521.70	71.0	580.67
.1	360.07	.1	412.06	.1	466.26	.1	522.86	.1	581.88
.2	361.09	.2	413.12	.2	467.37	.2	524.02	.2	583.09
.3	362.11	.3	414.18	.3	468.48	.3	525.18	.3	584.30
.4	363.13	.4	415.24	.4	469.59	.4	526.34	.4	585.51
.5	364.15	.5	416.31	.5	470.70	.5	527.50	.5	586.72
.6	365.17	.6	417.38	.6	471.81	.6	528.66	.6	587.93
.7	366.19	.7	418.45	.7	472.92	.7	529.82	.7	589.14
.8	367.22	.8	419.52	.8	474.03	.8	530.98	.8	590.35
.9	368.25	.9	420.59	.8	475.14	.9	532.14	.9	591.56
52.0	369.28	57.0	421.66	62.0	476.25	67.0	533.30	72.0	592.77
.1	370.31	.1	422.73	.1	477.37	.1	534.46	.1	593.99
.2	371.34	.2	423.80	.2	478.49	.2	535.62	.2	595.21
.3	372.37	.3	424.87	.3	479.61	.3	536.79	.3	596.43
.4	373.40	.4	425.94	.4	480.73	.4	537.96	.4	597.65
.5	374.43	.5	427.01	.5	481.85	.5	539.13	.5	598.87
.6	375.46	.6	428.08	.6	482.97	.6	540.30	.6	600.09
.7	376.49	.7	429.15	.7	484.09	.7	541.47	.7	601.31
.8	377.52	.8	430.22	.8	485.21	.8	542.64	.8	602.53
.9	378.55	.9	431.29	.9	486.33	.9	543.81	.9	603.75
53.0	379.58	58.0	432.37	63.0	487.46	68.0	544.98	73.0	604.98
.1	380.61	.1	433.45	.1	488.59	.1	546.15	.1	606.21
.2	381.64	.2	434.53	.2	489.72	.2	547.32	.2	607.44
.3	382.67	.3	435.61	.3	490.85	.3	548.49	.3	608.67
.4	383.70	.4	436.69	.4	491.98	.4	549.66	.4	609.90
.5	384.73	.5	437.77	.5	493.11	.5	550.84	.5	611.13
.6	385.76	.6	438.85	.6	494.24	.6	552.02	.6	612.36
.7	386.80	.7	439.93	.7	495.37	.7	553.20	.7	613.59
.8	387.84	.8	441.02	.8	496.50	.8	554.38	.8	614.82
.9	388.88	.9	442.11	.9	497.64	.9	555.56	.9	616.05
54.0	389.92	59.0	443.20	64.0	498.78	69.0	556.74	74.0	617.29
.1	390.96	.1	444.29	.1	499.92	.1	557.92	.1	618.53
.2	392.01	.2	445.38	.2	501.06	.2	559.10	.2	619.77
.3	393.06	.3	446.47	.3	502.20	.3	560.29	.3	621.01
.4	394.11	.4	447.56	.4	503.34	.4	561.48	.4	622.25
.5	395.16	.5	448.65	.5	504.48	.5	562.67	.5	623.49
.6	396.21	.6	449.74	.6	505.62	.6	563.86	.6	624.73
.7	397.26	.7	450.83	.7	506.76	.7	565.05	.7	625.98
.8	398.31	.8	451.92	.8	507.90	.8	566.25	.8	627.23
.9	399.36	.9	453.01	.9	509.04	.9	567.45	.9	628.48
55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65	75.0	629.73

TABLE 48.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	629.73	80.0	693.50	85.0	760.69	90.0	832.76	95.0	911.46
.1	630.98	.1	694.81	.1	762.08	.1	834.26	.1	913.12
.2	632.23	.2	696.12	.2	763.47	.2	835.76	.2	914.78
.3	633.48	.3	697.43	.3	764.86	.3	837.27	.3	916.44
.4	634.73	.4	698.74	.4	766.25	.4	838.78	.4	918.11
.5	635.98	.5	700.06	.5	767.65	.5	840.29	.5	919.79
.6	637.23	.6	701.38	.6	769.05	.6	841.80	.6	921.47
.7	638.48	.7	702.70	.7	770.45	.7	843.32	.7	923.16
.8	639.73	.8	704.02	.8	771.85	.8	844.84	.8	924.85
.9	640.98	.9	705.34	.9	773.25	.9	846.37	.9	926.54
76.0	642.23	81.0	706.66	86.0	774.66	91.0	847.90	96.0	928.24
.1	643.48	.1	707.98	.1	776.07	.1	849.43	.1	929.94
.2	644.73	.2	709.30	.2	777.48	.2	850.96	.2	931.64
.3	645.99	.3	710.62	.3	778.89	.3	852.50	.3	933.35
.4	647.25	.4	711.95	.4	780.30	.4	854.04	.4	935.06
.5	648.51	.5	713.28	.5	781.72	.5	855.58	.5	936.78
.6	649.77	.6	714.61	.6	783.14	.6	857.12	.6	938.50
.7	651.03	.7	715.94	.7	784.56	.7	858.67	.7	940.22
.8	652.29	.8	717.27	.8	785.98	.8	860.22	.8	941.95
.9	653.55	.9	718.60	.9	787.40	.9	861.77	.9	943.68
77.0	654.81	82.0	719.94	87.0	788.83	92.0	863.33	97.0	945.42
.1	656.08	.1	721.28	.1	790.26	.1	864.89	.1	947.17
.2	657.35	.2	722.62	.2	791.70	.2	866.46	.2	948.92
.3	658.62	.3	723.96	.3	793.14	.3	868.03	.3	950.68
.4	659.90	.4	725.30	.4	794.58	.4	869.61	.4	952.44
.5	661.18	.5	726.64	.5	796.02	.5	871.19	.5	954.21
.6	662.46	.6	727.98	.6	797.46	.6	872.77	.6	955.98
.7	663.74	.7	729.32	.7	798.91	.7	874.35	.7	957.76
.8	665.02	.8	730.66	.8	800.36	.8	875.93	.8	959.55
.9	666.30	.9	732.00	.9	801.81	.9	877.52	.9	961.34
78.0	667.58	83.0	733.35	88.0	803.26	93.0	879.11	98.0	963.14
.1	668.86	.1	734.70	.1	804.71	.1	880.70	.1	964.94
.2	670.14	.2	736.05	.2	806.16	.2	882.29	.2	966.75
.3	671.43	.3	737.40	.3	807.61	.3	883.88	.3	968.56
.4	672.72	.4	738.76	.4	809.07	.4	885.48	.4	970.38
.5	674.01	.5	740.12	.5	810.53	.5	887.08	.5	972.20
.6	675.30	.6	741.48	.6	811.99	.6	888.68	.6	974.02
.7	676.59	.7	742.84	.7	813.45	.7	890.29	.7	975.85
.8	677.88	.8	744.20	.8	814.92	.8	891.90	.8	977.58
.9	679.17	.9	745.56	.9	816.39	.9	893.51	.9	979.51
79.0	680.47	84.0	746.92	89.0	817.86	94.0	895.12	99.0	981.35
.1	681.77	.1	748.29	.1	819.34	.1	896.74	.1	983.19
.2	683.07	.2	749.66	.2	820.82	.2	898.36	.2	985.03
.3	684.37	.3	751.03	.3	822.30	.3	899.98	.3	986.88
.4	685.67	.4	752.40	.4	823.79	.4	901.61	.4	988.74
.5	686.97	.5	753.78	.5	825.28	.5	903.24	.5	990.60
.6	688.27	.6	755.16	.6	826.77	.6	904.88	.6	992.47
.7	689.57	.7	756.54	.7	828.26	.7	906.52	.7	994.35
.8	690.88	.8	757.92	.8	829.76	.8	908.16	.8	996.23
.9	692.19	.9	759.30	.9	831.26	.9	909.81	.9	998.11
80.0	693.50	85.0	760.69	90.0	832.76	95.0	911.46	100.0	1 000.00

TABLE 49.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F

[Total length of scale 1000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
0.0	0.00	5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90
.1	0.58	.1	28.37	.1	52.76	.1	74.89	.1	95.30
.2	1.16	.2	28.90	.2	53.22	.2	75.31	.2	95.70
.3	1.73	.3	29.43	.3	53.68	.3	75.73	.3	96.10
.4	2.31	.4	29.96	.4	54.14	.4	76.15	.4	96.50
.5	2.89	.5	30.48	.5	54.60	.5	76.57	.5	96.90
.6	3.47	.6	31.00	.6	55.06	.6	76.99	.6	97.30
.7	4.04	.7	31.51	.7	55.52	.7	77.41	.7	97.70
.8	4.62	.8	32.02	.8	55.98	.8	77.83	.8	98.11
.9	5.20	.9	32.53	.9	56.44	.9	78.25	.9	98.51
1.0	5.78	6.0	33.04	11.0	56.90	16.0	78.67	21.0	98.92
.1	6.36	.1	33.55	.1	57.36	.1	79.09	.1	99.33
.2	6.93	.2	34.05	.2	57.82	.2	79.51	.2	99.74
.3	7.50	.3	34.55	.3	58.28	.3	79.93	.3	100.15
.4	8.07	.4	35.05	.4	58.74	.4	80.35	.4	100.56
.5	8.64	.5	35.55	.5	59.20	.5	80.77	.5	100.97
.6	9.21	.6	36.05	.6	59.65	.6	81.19	.6	101.38
.7	9.78	.7	36.55	.7	60.10	.7	81.60	.7	101.79
.8	10.35	.8	37.05	.8	60.55	.8	82.01	.8	102.20
.9	10.92	.9	37.55	.9	61.00	.9	82.42	.9	102.61
2.0	11.49	7.0	38.05	12.0	61.45	17.0	82.83	22.0	103.02
.1	12.05	.1	38.54	.1	61.90	.1	83.24	.1	103.43
.2	12.61	.2	39.03	.2	62.35	.2	83.65	.2	103.84
.3	13.17	.3	39.52	.3	62.79	.3	84.06	.3	104.25
.4	13.73	.4	40.01	.4	63.23	.4	84.47	.4	104.66
.5	14.29	.5	40.50	.5	63.67	.5	84.88	.5	105.08
.6	14.85	.6	40.98	.6	64.11	.6	85.28	.6	105.50
.7	15.41	.7	41.46	.7	64.55	.7	85.69	.7	105.92
.8	15.97	.8	41.94	.8	64.99	.8	86.09	.8	106.34
.9	16.52	.9	42.42	.9	65.43	.9	86.49	.9	106.76
3.0	17.07	8.0	42.89	13.0	65.87	18.0	86.89	23.0	107.18
.1	17.62	.1	43.36	.1	66.31	.1	87.29	.1	107.60
.2	18.17	.2	43.83	.2	66.74	.2	87.69	.2	108.02
.3	18.72	.3	44.30	.3	67.17	.3	88.09	.3	108.44
.4	19.27	.4	44.77	.4	67.60	.4	88.50	.4	108.86
.5	19.82	.5	45.24	.5	68.03	.5	88.90	.5	109.28
.6	20.37	.6	45.72	.6	68.46	.6	89.30	.6	109.70
.7	20.91	.7	46.20	.7	68.89	.7	89.70	.7	110.12
.8	21.45	.8	46.67	.8	69.32	.8	90.10	.8	110.54
.9	21.99	.9	47.14	.9	69.75	.9	90.50	.9	110.96
4.0	22.53	9.0	47.61	14.0	70.18	19.0	90.90	24.0	111.38
.1	23.07	.1	48.08	.1	70.61	.1	91.30	.1	111.81
.2	23.60	.2	48.55	.2	71.04	.2	91.70	.2	112.24
.3	24.13	.3	49.02	.3	71.47	.3	92.10	.3	112.67
.4	24.66	.4	49.49	.4	71.90	.4	92.50	.4	113.10
.5	25.19	.5	49.96	.5	72.33	.5	92.90	.5	113.53
.6	25.72	.6	50.43	.6	72.76	.6	93.30	.6	113.96
.7	26.25	.7	50.90	.7	73.19	.7	93.70	.7	114.39
.8	26.78	.8	51.37	.8	73.62	.8	94.10	.8	114.82
.9	27.31	.9	51.84	.9	74.05	.9	94.50	.9	115.25
5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90	25.0	115.68

TABLE 49.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	115.68	30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59
.1	116.11	.1	138.75	.1	164.92	.1	195.79	.1	231.35
.2	116.54	.2	139.23	.2	165.49	.2	196.46	.2	232.11
.3	116.97	.3	139.71	.3	166.06	.3	197.13	.3	232.87
.4	117.40	.4	140.20	.4	166.63	.4	197.80	.4	233.63
.5	117.83	.5	140.69	.5	167.20	.5	198.47	.5	234.39
.6	118.27	.6	141.18	.6	167.78	.6	199.14	.6	235.16
.7	118.71	.7	141.67	.7	168.36	.7	199.82	.7	235.93
.8	119.15	.8	142.16	.8	168.94	.8	200.50	.8	236.71
.9	119.59	.9	142.65	.9	169.53	.9	201.18	.9	237.49
26.0	120.03	31.0	143.14	36.0	170.12	41.0	201.86	46.0	238.28
.1	120.47	.1	143.63	.1	170.71	.1	202.55	.1	239.06
.2	120.91	.2	144.12	.2	171.30	.2	203.24	.2	239.84
.3	121.35	.3	144.61	.3	171.89	.3	203.93	.3	240.62
.4	121.79	.4	145.10	.4	172.48	.4	204.62	.4	241.40
.5	122.23	.5	145.59	.5	173.08	.5	205.31	.5	242.18
.6	122.67	.6	146.09	.6	173.68	.6	206.00	.6	242.97
.7	123.12	.7	146.59	.7	174.28	.7	206.70	.7	243.76
.8	123.57	.8	147.11	.8	174.88	.8	207.40	.8	244.55
.9	124.02	.9	147.63	.9	175.48	.9	208.10	.9	245.34
27.0	124.47	32.0	148.15	37.0	176.08	42.0	208.80	47.0	246.14
.1	124.92	.1	148.67	.1	176.69	.1	209.50	.1	246.94
.2	125.37	.2	149.19	.2	177.30	.2	210.20	.2	247.74
.3	125.82	.3	149.71	.3	177.91	.3	210.90	.3	248.54
.4	126.27	.4	150.23	.4	178.52	.4	211.60	.4	249.35
.5	126.72	.5	150.75	.5	179.13	.5	212.31	.5	250.16
.6	127.17	.6	151.27	.6	179.75	.6	213.02	.6	250.97
.7	127.62	.7	151.79	.7	180.37	.7	213.73	.7	251.79
.8	128.07	.8	152.31	.8	180.99	.8	214.44	.8	252.61
.9	128.52	.9	152.84	.9	181.62	.9	215.15	.9	253.43
28.0	128.98	33.0	153.37	38.0	182.25	43.0	215.87	48.0	254.25
.1	129.44	.1	153.90	.1	182.88	.1	216.59	.1	255.07
.2	129.90	.2	154.43	.2	183.51	.2	217.31	.2	255.89
.3	130.36	.3	154.96	.3	184.14	.3	218.03	.3	256.71
.4	130.82	.4	155.50	.4	184.77	.4	218.75	.4	257.53
.5	131.28	.5	156.04	.5	185.40	.5	219.48	.5	258.36
.6	131.74	.6	156.58	.6	186.03	.6	220.21	.6	259.19
.7	132.20	.7	157.12	.7	186.67	.7	220.94	.7	260.02
.8	132.66	.8	157.66	.8	187.31	.8	221.67	.8	260.85
.9	133.12	.9	158.21	.9	187.95	.9	222.40	.9	261.69
29.0	133.58	34.0	158.76	39.0	188.59	44.0	223.14	49.0	262.53
.1	134.04	.1	159.31	.1	189.23	.1	223.88	.1	263.37
.2	134.51	.2	159.86	.2	189.88	.2	224.62	.2	264.21
.3	134.98	.3	160.42	.3	190.53	.3	225.36	.3	265.05
.4	135.45	.4	160.98	.4	191.18	.4	226.10	.4	265.89
.5	135.92	.5	161.54	.5	191.83	.5	226.84	.5	266.74
.6	136.39	.6	162.10	.6	192.48	.6	227.59	.6	267.59
.7	136.86	.7	162.66	.7	193.13	.7	228.34	.7	268.44
.8	137.33	.8	163.22	.8	193.79	.8	229.09	.8	269.30
.9	137.80	.9	163.78	.9	194.45	.9	229.84	.9	270.16
30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59	50.0	271.02

TABLE 49.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
50.0	271.02	55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10
.1	271.88	.1	316.88	.1	366.04	.1	419.50	.1	477.31
.2	272.74	.2	317.82	.2	367.07	.2	420.60	.2	478.52
.3	273.60	.3	318.76	.3	368.10	.3	421.71	.3	479.73
.4	274.47	.4	319.70	.4	369.13	.4	422.82	.4	480.94
.5	275.34	.5	320.65	.5	370.16	.5	423.93	.5	482.15
.6	276.21	.6	321.60	.6	371.20	.6	425.05	.6	483.36
.7	277.08	.7	322.55	.7	372.24	.7	426.17	.7	484.57
.8	277.95	.8	323.50	.8	373.28	.8	427.29	.8	485.78
.9	278.82	.9	324.45	.9	374.32	.9	428.41	.9	487.00
51.0	279.70	56.0	325.40	61.0	375.36	66.0	429.54	71.0	488.22
.1	280.58	.1	326.35	.1	376.40	.1	430.67	.1	489.45
.2	281.46	.2	327.31	.2	377.44	.2	431.80	.2	490.68
.3	282.34	.3	328.27	.3	378.49	.3	432.93	.3	491.91
.4	283.22	.4	329.23	.4	379.54	.4	434.06	.4	493.14
.5	284.10	.5	330.19	.5	380.60	.5	435.19	.5	494.37
.6	284.98	.6	331.15	.6	381.66	.6	436.32	.6	495.60
.7	285.87	.7	332.11	.7	382.72	.7	437.46	.7	496.84
.8	286.76	.8	333.07	.8	383.78	.8	438.60	.8	498.08
.9	287.65	.9	334.03	.9	384.84	.9	439.75	.9	499.32
52.0	288.54	57.0	334.99	62.0	385.91	67.0	440.90	72.0	500.56
.1	289.43	.1	335.95	.1	386.98	.1	442.05	.1	501.80
.2	290.32	.2	336.92	.2	388.05	.2	443.20	.2	503.05
.3	291.21	.3	337.89	.3	389.12	.3	444.35	.3	504.30
.4	292.10	.4	338.87	.4	390.19	.4	445.50	.4	505.56
.5	292.99	.5	339.85	.5	391.26	.5	446.65	.5	506.82
.6	293.89	.6	340.83	.6	392.33	.6	447.80	.6	508.08
.7	294.79	.7	341.81	.7	393.40	.7	448.95	.7	509.34
.8	295.69	.8	342.79	.8	394.47	.8	450.11	.8	510.60
.9	296.59	.9	343.78	.9	395.55	.9	451.26	.9	511.86
53.0	297.50	58.0	344.78	63.0	396.63	68.0	452.42	73.0	513.13
.1	298.41	.1	345.78	.1	397.71	.1	453.58	.1	514.40
.2	299.32	.2	346.78	.2	398.79	.2	454.74	.2	515.67
.3	300.23	.3	347.78	.3	399.87	.3	455.91	.3	516.94
.4	301.14	.4	348.78	.4	400.95	.4	457.08	.4	518.21
.5	302.05	.5	349.78	.5	402.03	.5	458.25	.5	519.48
.6	302.96	.6	350.78	.6	403.11	.6	459.43	.6	520.76
.7	303.87	.7	351.78	.7	404.19	.7	460.61	.7	522.04
.8	304.78	.8	352.78	.8	405.27	.8	461.79	.8	523.32
.9	305.70	.9	353.79	.9	406.36	.9	462.98	.9	524.60
54.0	306.62	59.0	354.80	64.0	407.45	69.0	464.17	74.0	525.89
.1	307.55	.1	355.81	.1	408.54	.1	465.36	.1	527.18
.2	308.48	.2	356.82	.2	409.63	.2	466.55	.2	528.47
.3	309.41	.3	357.84	.3	410.72	.3	467.74	.3	529.76
.4	310.34	.4	358.86	.4	411.81	.4	468.93	.4	531.05
.5	311.27	.5	359.88	.5	412.90	.5	470.12	.5	532.34
.6	312.20	.6	360.90	.6	414.00	.6	471.31	.6	533.63
.7	313.13	.7	361.92	.7	415.10	.7	472.50	.7	534.92
.8	314.06	.8	362.95	.8	416.20	.8	473.70	.8	536.21
.9	315.00	.9	363.98	.9	417.30	.9	474.90	.9	537.51
55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10	75.0	538.81

TABLE 49.—Master Scale for the Graduation of Hydrometers to Indicate Percentages of Ethyl Alcohol by Volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	538.81	80.0	607.33	85.0	682.71	90.0	767.67	95.0	868.34
.1	540.12	.1	608.77	.1	684.31	.1	769.50	.1	870.60
.2	541.43	.2	610.21	.2	685.91	.2	771.33	.2	872.87
.3	542.74	.3	611.65	.3	687.52	.3	773.16	.3	875.15
.4	544.05	.4	613.09	.4	689.13	.4	774.99	.4	877.44
.5	545.37	.5	614.53	.5	690.74	.5	776.83	.5	879.74
.6	546.69	.6	615.97	.6	692.36	.6	778.68	.6	882.05
.7	548.01	.7	617.42	.7	693.98	.7	780.54	.7	884.37
.8	549.33	.8	618.87	.8	695.60	.8	782.41	.8	886.71
.9	550.66	.9	620.33	.9	697.23	.9	784.29	.9	889.06
76.0	552.00	81.0	621.79	86.0	698.86	91.0	786.18	96.0	891.43
.1	553.34	.1	623.26	.1	700.50	.1	788.08	.1	893.82
.2	554.68	.2	624.73	.2	702.14	.2	789.98	.2	896.22
.3	556.02	.3	626.20	.3	703.79	.3	791.88	.3	898.62
.4	557.36	.4	627.67	.4	705.44	.4	793.78	.4	901.03
.5	558.70	.5	629.14	.5	707.10	.5	795.69	.5	903.45
.6	560.05	.6	630.62	.6	708.76	.6	797.62	.6	905.89
.7	561.40	.7	632.10	.7	710.42	.7	799.57	.7	908.34
.8	562.75	.8	633.58	.8	712.08	.8	801.52	.8	910.80
.9	564.10	.9	635.07	.9	713.74	.9	803.49	.9	913.27
77.0	565.45	82.0	636.56	87.0	715.41	92.0	805.46	97.0	915.75
.1	566.81	.1	638.05	.1	717.08	.1	807.44	.1	918.25
.2	568.17	.2	639.54	.2	718.75	.2	809.42	.2	920.77
.3	569.53	.3	641.03	.3	720.43	.3	811.40	.3	923.31
.4	570.89	.4	642.53	.4	722.11	.4	813.39	.4	925.88
.5	572.25	.5	644.03	.5	723.80	.5	815.38	.5	928.46
.6	573.62	.6	645.54	.6	725.50	.6	817.38	.6	931.05
.7	574.99	.7	647.05	.7	727.20	.7	819.40	.7	933.66
.8	576.37	.8	648.57	.8	728.90	.8	821.42	.8	936.28
.9	577.75	.9	650.09	.9	730.60	.9	823.45	.9	938.93
78.0	579.13	83.0	651.61	88.0	732.31	93.0	825.49	98.0	941.61
.1	580.52	.1	653.13	.1	734.02	.1	827.54	.1	944.33
.2	581.92	.2	654.65	.2	735.74	.2	829.60	.2	947.06
.3	583.32	.3	656.18	.3	737.46	.3	831.67	.3	949.80
.4	584.72	.4	657.71	.4	739.19	.4	833.74	.4	952.56
.5	586.12	.5	659.24	.5	740.93	.5	835.82	.5	955.35
.6	587.52	.6	660.77	.6	742.68	.6	837.90	.6	958.16
.7	588.92	.7	662.31	.7	744.43	.7	840.00	.7	961.00
.8	590.32	.8	663.85	.8	746.19	.8	842.12	.8	963.86
.9	591.72	.9	665.40	.9	747.95	.9	844.25	.9	966.74
79.0	593.12	84.0	666.96	89.0	749.72	94.0	846.40	99.0	969.64
.1	594.53	.1	668.52	.1	751.49	.1	848.56	.1	972.56
.2	595.94	.2	670.08	.2	753.27	.2	850.73	.2	975.52
.3	597.35	.3	671.64	.3	755.05	.3	852.90	.3	978.50
.4	598.77	.4	673.21	.4	756.84	.4	855.08	.4	981.50
.5	600.19	.5	674.79	.5	758.64	.5	857.26	.5	984.52
.6	601.61	.6	676.37	.6	760.45	.6	859.46	.6	987.55
.7	603.04	.7	677.95	.7	762.25	.7	861.67	.7	990.61
.8	604.47	.8	679.53	.8	764.05	.8	863.88	.8	993.71
.9	605.90	.9	681.12	.9	765.86	.9	866.10	.9	996.84
80.0	607.33	85.0	692.71	90.0	767.67	95.0	868.34	100.0	1 000.00

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DEPARTMENT OF COMMERCE
U.S. BUREAU OF STANDARDS
George K. Burgess, Director

**STANDARD DENSITY
AND
VOLUMETRIC TABLES**

CIRCULAR OF THE BUREAU OF STANDARDS, No. 19

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS
George K. Burgess, Director

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**STANDARD DENSITY AND
VOLUMETRIC TABLES**

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STANDARD DENSITY AND VOLUMETRIC TABLES

ABSTRACT

This circular contains standard density tables and others of a similar nature most often required in physical and chemical laboratories. For example, the density of water at all temperatures from 0° C. to 102° C.; the density of various percentages of ethyl alcohol at various temperatures; the density and pounds per gallon of milk and cream, and of American petroleum oils; temperature corrections to the indications of hydrometers in alcohol, sugar, petroleum oil, and sulphuric acid solutions. Tables are also given showing the relation between degreed Baumé and specific gravity for both heavy and light liquids; the relation of degrees A. P. I. and specific gravity; the capacities of glass vessels from the weight of water contained or delivered; and master scales for the graduation of hydrometers (alcoholometers).

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INTRODUCTION

The wide application of hydrometers as measuring instruments in the collection of revenues in commerce and in the industries makes it very important to define the various scales of indication of these instruments in terms of fundamental units.

The confusion and discordance heretofore resulting from the use of various insufficiently defined hydrometer scales, and the lack of opportunity for verifying standards on a uniform basis, led the bureau to investigate the problems connected with hydrometry and to prepare standard density tables for definition of hydrometer scales.

In bureau circular No. 16 the conditions are announced under which the testing of hydrometers will be conducted, and specifications are given as to the construction, standardization, and accuracy required for hydrometers in order that they be approved as precision instruments.

The present circular comprises the density tables which have been adopted for definition of hydrometer scales, auxiliary tables which have been prepared for reduction of hydrometer readings, tables for computation of volumetric capacity, and others of similar nature giving physical constants for which the bureau receives frequent inquiries.

In all tables found in this circular the term *density* is used to represent the *mass per unit volume* and is expressed in *grams per milliliter*.

The term *specific gravity* is used to express the *relative masses of equal volumes* of the liquid in question and of water, *each liquid being at a definitely stated temperature*. For example, specific gravity at $\frac{60^{\circ}}{60^{\circ}}$ F. means the specific gravity of the liquid at 60° F. referred to water at 60° F. as unity.

The density values in Tables 1, 2, 8, 12, 13, 32, and 33 are numerically the same as specific gravities at the various temperatures referred to water at 4° C. as unity.

For the sake of uniformity the same abbreviation, D, with the proper temperature basis, is used for both density and specific gravity.

GEORGE K. BURGESS,
Director.

Approved:
HERBERT HOOVER,
Secretary.

TABLE 1.—Density¹ (in grams per milliliter) of mixtures of ethyl alcohol and water²

Per cent alcohol by weight	Temperature						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
0	0.99973	0.99913	0.99823	0.99708	0.99568	0.99406	0.99225
1	785	725	636	520	379	217	034
2	602	542	453	336	194	031	.98846
3	426	365	275	167	014	.98849	063
4	258	195	103	.98984	.98839	672	485
5	098	082	.98938	817	670	501	311
6	.98946	.98877	780	656	507	335	142
7	801	729	627	500	347	172	.97975
8	660	584	478	346	189	009	806
9	524	442	331	193	031	.97846	641
10	393	304	187	043	.97875	685	475
11	267	171	047	.97907	723	527	312
12	145	041	.97910	753	573	371	150
13	026	.97914	775	611	424	216	.96989
14	.97911	790	643	472	278	063	829
15	800	609	514	334	133	.96911	670
16	692	552	387	199	.96900	780	512
17	583	433	259	062	844	607	352
18	473	313	139	.96923	697	452	189
19	363	191	.96907	782	547	294	023
20	252	068	864	639	395	134	.96856
21	139	.96944	720	495	242	.96973	687
22	024	818	592	348	067	809	516
23	.96907	689	453	199	.96929	643	343
24	787	558	312	048	769	476	168
25	665	424	168	.96895	607	306	.94991
26	539	287	020	728	442	138	810
27	406	144	.96867	576	272	.94955	625
28	268	.96906	710	410	098	774	438
29	125	844	548	241	.94922	590	248
30	.96977	686	382	067	741	403	055
31	823	524	212	.94890	557	214	.93890
32	665	357	038	709	370	021	662
33	502	186	.94860	525	180	.93825	461
34	334	011	679	337	.93986	626	257
35	162	.94832	494	146	790	425	051
36	.94986	650	306	.93952	591	221	.92843
37	806	464	114	756	390	016	634
38	620	273	.93919	556	186	.92808	422
39	431	079	720	353	.92979	597	208
40	238	.93882	518	148	770	385	.91992
41	042	682	314	.92940	558	170	774
42	.93842	478	107	729	344	.91962	554
43	639	271	.92997	516	128	733	332
44	433	062	685	301	.91910	513	106
45	226	.92852	472	085	692	291	.90884
46	017	640	257	.91868	472	069	690
47	.92806	426	041	649	250	.90845	434
48	593	211	.91823	429	028	621	207
49	379	.91995	604	208	.90805	396	.89979
50	162	776	384	.90985	580	168	750

¹ The density values given in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4° C. as unity.

² Tables 1, 2, 3, 4, 5, 6, and 7, of this circular are based on the work done at this bureau and published in the Bulletin of the Bureau of Standards, vol. 9, No. 3. (Reprint No. 197.)

TABLE 1.—Density (in grams per milliliter) of mixtures of ethyl alcohol and water—Continued

Per cent alcohol by weight	Temperature						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
50	0.92162	0.91776	0.91384	0.90965	0.90680	0.90168	0.89750
51	.91943	.565	.180	.780	.353	.89940	.519
52	.723	.333	.90636	.534	.125	.710	.288
53	.502	.110	.711	.307	.89996	.479	.066
54	.279	.90685	.485	.079	.667	.248	.88823
55	.055	.659	.258	.80850	.437	.016	.589
56	.90631	.433	.031	.621	.206	.88784	.356
57	.607	.207	.89603	.392	.88975	.552	.122
58	.381	.89980	.574	.162	.744	.319	.87888
59	.154	.752	.344	.88931	.512	.085	.653
60	.89927	.523	.113	.699	.278	.87851	.417
61	.696	.293	.88882	.466	.044	.615	.180
62	.468	.062	.650	.233	.87809	.379	.86943
63	.237	.88830	.417	.87998	.574	.142	.705
64	.006	.597	.183	.763	.337	.86905	.466
65	.88774	.364	.87948	.527	.100	.667	.227
66	.541	.130	.713	.291	.86863	.429	.85987
67	.306	.87895	.477	.064	.625	.190	.747
68	.074	.660	.241	.86817	.387	.85950	.507
69	.87839	.424	.004	.579	.148	.710	.266
70	.602	.187	.86766	.340	.85908	.470	.025
71	.365	.86949	.527	.100	.667	.228	.84783
72	.127	.710	.287	.86859	.426	.84996	.540
73	.86888	.470	.047	.618	.184	.743	.297
74	.648	.229	.85806	.376	.84941	.500	.063
75	.406	.85968	.564	.134	.698	.257	.83809
76	.168	.747	.322	.84891	.455	.013	.564
77	.85927	.505	.079	.647	.211	.83768	.319
78	.685	.262	.84835	.403	.63966	.523	.074
79	.442	.018	.590	.158	.720	.277	.82827
80	.197	.84772	.344	.83911	.473	.029	.578
81	.84950	.525	.096	.664	.224	.82780	.329
82	.702	.277	.83848	.415	.82974	.530	.079
83	.453	.028	.599	.164	.724	.279	.81828
84	.203	.83777	.348	.82913	.473	.027	.576
85	.83951	.525	.095	.660	.220	.81774	.322
86	.697	.271	.82840	.405	.81965	.519	.067
87	.441	.014	.583	.148	.708	.262	.80811
88	.181	.82754	.323	.81888	.448	.003	.552
89	.82919	.492	.062	.626	.186	.80742	.291
90	.654	.227	.81797	.362	.80922	.478	.028
91	.386	.81959	.529	.094	.655	.211	.79761
92	.114	.688	.257	.80823	.384	.79941	.491
93	.81839	.413	.80983	.549	.111	.669	.220
94	.561	.134	.705	.272	.79635	.393	.78947
95	.278	.80652	.424	.79991	.555	.114	.670
96	.80991	.566	.138	.706	.271	.78831	.388
97	.698	.274	.79846	.415	.78981	.542	.100
98	.399	.79975	.547	.117	.684	.247	.77806
99	.094	.670	.243	.78814	.382	.77946	.507
100	.79784	.360	.78934	.506	.073	.641	.203

TABLE 2.—Density¹ (in grams per milliliter) of mixtures of ethyl alcohol and water at 20° C.

[* indicates change in first two decimal places. See next line, column 0]

Per cent alcohol by weight	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
0	0.99823	804	785	766	748	729	710	692	673	655
1	636	618	599	581	562	544	525	507	489	471
2	453	435	417	399	381	363	345	327	310	292
3	275	257	240	222	205	188	171	154	137	120
4	108	087	070	053	037	020	003	*987	*971	*954
5	.98038	922	906	890	874	859	843	827	811	796
6	780	765	749	734	718	703	688	673	658	642
7	627	612	597	582	567	553	538	523	508	493
8	478	463	449	434	419	404	389	374	360	345
9	331	316	301	287	273	258	244	229	215	201
10	187	172	158	144	130	117	103	089	075	061
11	047	033	019	006	*992	*978	*964	*951	*937	*923
12	.97910	896	883	869	855	842	828	815	801	788
13	775	761	748	735	722	709	696	683	670	657
14	643	630	617	604	591	578	565	552	539	526
15	514	501	488	475	462	450	438	425	412	400
16	387	374	361	349	336	323	310	297	284	272
17	259	246	233	220	207	194	181	168	155	142
18	129	116	103	089	076	063	050	037	024	010
19	.96997	984	971	957	944	931	917	904	891	877
20	864	850	837	823	810	796	783	769	756	742
21	729	716	702	688	675	661	647	634	620	606
22	592	578	564	551	537	523	509	495	481	467
23	453	439	425	411	396	382	368	354	340	326
24	312	297	283	269	254	240	225	211	196	182
25	168	153	139	124	109	094	080	065	050	035
26	020	005	*990	*975	*959	*944	*929	*914	*898	*883
27	.95867	851	836	820	805	789	773	757	742	726
28	710	694	678	662	646	630	613	597	581	565
29	548	532	516	499	483	466	450	433	416	400
30	382	365	349	332	315	298	281	264	247	230
31	212	195	178	161	143	126	108	091	074	056
32	038	020	003	*985	*967	*950	*932	*914	*896	*878
33	.94860	842	824	806	788	770	752	734	715	697
34	679	660	642	624	605	587	568	550	531	512
35	494	475	456	438	419	400	382	363	344	325
36	306	287	268	249	230	211	192	172	153	134
37	114	095	075	056	036	017	*997	*978	*958	*939
38	.93919	899	879	859	840	820	800	780	760	740
39	720	700	680	660	640	620	599	579	559	539
40	518	498	478	458	437	417	396	376	356	335
41	314	294	273	253	232	212	191	170	149	129
42	107	086	065	044	023	002	*981	*960	*939	*918
43	.92897	876	855	834	812	791	770	749	728	707
44	685	664	642	621	600	579	557	536	515	498
45	472	450	429	408	386	365	343	322	300	279
46	257	236	214	193	171	150	128	106	085	063
47	041	019	*997	*976	*954	*932	*910	*889	*867	*845
48	.91823	801	780	758	736	714	692	670	648	626
49	604	582	560	538	516	494	472	450	428	406
50	384	361	339	317	295	272	250	228	206	183

¹ The density values given in this table are numerically the same as specific gravity at 20° C. in terms of water at 4° C. as unity.

TABLE 2.—Density (in grams per milliliter) of mixtures of ethyl alcohol and water at 20° C.—Continued

[* indicates change in first two decimal places. See next line, column 0]

Per cent alcohol by weight	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
50	0.91384	361	339	317	295	272	250	228	206	183
51	160	138	116	093	071	049	026	004	*981	*959
52	.90086	914	891	869	846	824	801	779	756	734
53	711	689	666	644	621	598	576	553	531	508
54	485	463	440	417	395	372	349	327	304	281
55	258	236	213	190	167	145	122	099	076	054
56	031	008	*985	*962	*939	*917	*894	*871	*848	*825
57	.89803	780	757	734	711	688	665	643	620	597
58	574	551	528	505	482	459	436	413	390	367
59	344	321	298	275	252	229	206	183	160	137
60	113	090	067	044	021	*998	*975	*951	*928	*905
61	.88882	859	836	812	789	766	743	720	696	673
62	650	626	603	580	557	533	510	487	463	440
63	417	393	370	347	323	300	277	253	230	206
64	183	160	136	113	089	066	042	019	*995	*972
65	.87948	925	901	878	854	831	807	784	760	737
66	713	689	666	642	619	595	572	548	524	501
67	477	454	430	406	383	359	336	312	288	265
68	241	218	194	170	147	123	099	075	052	028
69	004	*981	*957	*933	*909	*885	*862	*838	*814	*790
70	.86766	742	718	694	671	647	622	599	575	551
71	527	503	479	455	431	407	383	359	335	311
72	287	263	239	215	191	167	143	119	095	071
73	047	022	*998	*974	*950	*926	*902	*878	*854	*830
74	.85806	781	757	733	709	685	661	636	612	588
75	564	540	515	491	467	443	419	394	370	346
76	322	297	273	249	225	200	176	152	128	103
77	079	055	031	006	*982	*958	*933	*909	*884	*860
78	.84835	811	787	762	738	713	689	664	640	615
79	590	566	541	517	492	467	443	418	393	369
80	344	319	294	270	245	220	196	171	146	121
81	096	072	047	022	*997	*972	*947	*923	*898	*873
82	.83848	823	798	773	748	723	698	674	649	624
83	599	574	549	523	498	473	448	423	398	373
84	348	323	297	272	247	222	196	171	146	120
85	095	070	044	019	*994	*968	*943	*917	*892	*866
86	.82840	815	789	763	738	712	686	660	635	609
87	563	537	511	485	459	433	407	381	355	329
88	323	297	271	245	219	193	167	140	114	088
89	062	035	009	*983	*956	*930	*903	*877	*850	*824
90	.81797	770	744	717	690	664	637	610	583	556
91	529	502	475	448	421	394	366	339	312	285
92	267	230	203	175	148	120	093	066	038	010
93	.80683	965	928	900	872	844	817	789	761	733
94	705	677	649	621	593	565	537	509	480	452
95	424	396	367	338	310	281	253	224	195	166
96	138	109	080	051	022	*993	*963	*934	*905	*875
97	.79646	816	787	757	727	698	668	638	608	578
98	547	517	487	456	426	396	365	335	305	274
99	243	213	182	151	120	089	059	028	*997	*966
100	.78634	-----	-----	-----	-----	-----	-----	-----	-----	-----

TABLE 3.—Specific gravity at 60° F. $\left(\frac{15^{\circ}56}{15^{\circ}56} C.\right)$ of mixtures (by volume) of ethyl alcohol and water

[* Indicates change in first two decimal places. See next line, column 0]

Per cent alcohol by volume at 60° F.	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
0	1.00000	*985	*970	*955	*940	*925	*910	*895	*880	*865
1	.99850	835	820	806	791	776	761	747	732	717
2	703	688	674	659	645	630	616	602	587	573
3	559	545	531	516	502	488	474	460	446	432
4	419	405	391	378	364	350	336	323	309	296
5	282	269	255	242	228	215	202	189	176	163
6	150	137	124	111	098	085	073	060	047	035
7	022	009	*997	*984	*972	*960	*947	*935	*923	*911
8	.99899	887	875	863	851	838	826	814	803	791
9	779	767	755	743	731	720	708	696	684	672
10	661	649	637	625	614	602	590	579	567	556
11	544	532	521	509	496	487	475	464	452	441
12	430	419	408	396	385	374	363	352	341	330
13	319	308	297	286	275	264	254	243	232	221
14	210	200	190	179	168	157	147	136	125	115
15	104	093	083	072	062	051	040	030	019	009
16	.97998	988	977	967	956	946	936	925	915	905
17	895	885	875	864	854	844	834	824	814	804
18	794	784	774	764	754	744	734	724	714	704
19	694	684	674	664	654	645	635	625	615	605
20	596	586	576	566	556	546	536	526	516	506
21	496	486	476	466	456	446	436	425	415	405
22	395	385	375	365	354	344	334	324	313	303
23	293	283	272	262	252	241	231	221	210	200
24	189	179	168	158	147	137	126	116	105	095
25	084	073	063	052	042	031	020	010	*999	*988
26	.96978	967	957	946	935	924	914	903	892	881
27	870	859	848	837	826	815	804	793	782	771
28	760	749	738	727	715	704	693	682	671	659
29	648	637	625	614	603	591	580	568	557	546
30	534	522	511	499	488	476	464	453	441	429
31	418	406	394	382	370	358	346	334	321	309
32	296	284	271	259	246	234	221	209	196	183
33	170	157	144	132	119	106	093	080	067	054
34	041	028	015	002	*988	*975	*962	*948	*935	*921
35	.95908	894	881	867	854	840	826	812	798	784
36	770	756	742	728	714	700	685	671	657	643
37	628	614	599	585	570	556	541	526	512	497
38	482	467	452	437	422	408	393	378	362	347
39	332	317	302	286	271	256	240	225	209	194
40	178	162	147	131	115	100	084	068	052	036
41	020	004	*988	*972	*956	*940	*923	*907	*891	*875
42	.94858	842	825	809	792	776	759	743	726	710
43	698	676	660	643	626	609	592	575	558	541
44	524	507	490	473	455	438	421	403	386	369
45	351	334	316	298	281	263	245	228	210	192
46	174	156	138	120	102	084	066	048	030	011
47	.93993	975	956	938	920	901	883	864	845	827
48	808	789	771	752	733	714	695	676	657	638
49	619	600	581	562	543	523	504	485	465	446
50	426	407	387	368	348	328	309	289	270	250

TABLE 3.—Specific gravity at 60° F. $\left(\frac{15.56}{15.56}^{\circ}\text{C.}\right)$ of mixtures (by volume) of ethyl alcohol and water—Continued

[* indicates change in first two decimal places. See next line, column 0]

Per cent alcohol by volume at 60° F.	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
50	0.98426	407	387	368	348	328	309	289	270	250
51	230	210	190	171	151	131	111	091	071	051
52	081	011	*991	*971	*951	*931	*911	*890	*870	*850
53	.92830	810	789	769	749	728	708	688	667	647
54	626	605	585	564	544	523	502	482	461	440
55	419	398	377	357	336	315	294	273	252	231
56	210	189	168	147	126	105	084	062	041	020
57	.91999	978	956	935	914	892	871	849	827	806
58	784	762	741	719	697	675	653	631	610	588
59	565	543	521	499	477	455	433	410	388	366
60	344	322	299	277	255	232	210	188	165	143
61	120	097	075	052	030	007	*984	*962	*939	*916
62	.90893	870	847	825	802	779	756	733	710	687
63	664	641	618	595	572	549	526	503	480	457
64	434	411	388	365	341	318	295	272	249	225
65	202	179	155	132	108	085	061	038	014	*991
66	.89967	943	920	896	872	848	825	801	777	753
67	729	705	681	657	633	609	585	561	537	513
68	489	465	441	416	392	368	343	319	295	270
69	245	220	196	171	147	122	098	073	048	024
70	.88999	974	950	925	900	875	850	825	801	776
71	751	725	700	675	650	625	600	574	549	524
72	499	474	448	423	397	372	346	321	296	270
73	244	218	193	167	141	116	090	064	039	013
74	.87987	961	935	910	884	858	832	806	780	754
75	728	702	676	650	623	597	571	545	518	492
76	465	439	412	386	359	332	306	279	252	226
77	199	172	145	118	092	065	038	011	*984	*957
78	.86929	902	875	847	820	793	766	738	711	684
79	656	629	601	574	546	518	491	463	435	408
80	380	352	324	296	269	241	213	185	157	129
81	100	072	044	015	*987	*959	*931	*902	*874	*846
82	.85817	789	760	732	703	674	646	617	588	560
83	531	502	473	444	415	386	357	328	299	270
84	240	211	181	152	122	093	063	033	004	*974
85	.84944	914	884	854	824	794	764	734	703	673
86	642	612	581	551	520	490	459	428	398	367
87	336	305	274	243	212	181	150	119	088	056
88	025	*994	*962	*930	*899	*867	*835	*803	*771	*739
89	.83707	675	643	610	578	545	513	480	447	415
90	382	349	315	282	249	216	183	150	116	083
91	049	015	*981	*947	*913	*879	*845	*810	*776	*741
92	.82705	670	635	600	565	529	494	458	423	387
93	351	315	279	243	206	170	133	096	059	022
94	.81984	947	909	871	834	796	757	719	681	642
95	603	564	525	486	446	407	367	327	287	247
96	206	165	125	084	042	001	*960	*918	*876	*834
97	.80792	750	707	664	620	577	533	489	445	401
98	356	311	265	219	173	127	080	033	*985	*937
99	.79689	841	792	743	693	643	593	543	492	441
100	389									

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which Tables 1, 2, 3, 5, 6, and 7 are calculated. The hydrometer is assumed to be of Jena 16^{mm} glass. For the per cents not given between 40 and 80, linear interpolation of the tabulated corrections will give results sufficiently exact for most purposes.]

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume												
	0	1	2	3	4	5	6	7	8	9	10	11	12
	Add to observed per cent alcohol												
50	0.37	0.38	0.39	0.40	0.42	0.45	0.48	0.52	0.56	0.61	0.66	0.74	0.81
51	.34	.35	.36	.37	.39	.41	.44	.47	.51	.56	.61	.68	.75
52	.32	.32	.33	.34	.35	.38	.40	.43	.47	.51	.55	.62	.68
53	.29	.30	.30	.31	.32	.34	.36	.39	.42	.46	.49	.55	.60
54	.26	.26	.26	.27	.28	.29	.32	.34	.36	.40	.43	.48	.52
55	.22	.22	.23	.23	.24	.25	.27	.29	.31	.34	.37	.40	.44
56	.18	.18	.18	.18	.19	.20	.22	.24	.25	.28	.30	.33	.36
57	.14	.14	.14	.14	.14	.15	.17	.18	.19	.21	.23	.25	.27
58	.09	.10	.10	.10	.10	.10	.11	.12	.13	.14	.16	.16	.18
59	.05	.05	.05	.05	.05	.05	.06	.06	.06	.07	.08	.08	.09
Subtract from observed per cent alcohol													
61	-----	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10
62	-----	.10	.11	.12	.12	.13	.14	.14	.16	.16	.17	.18	.20
63	-----	.16	.17	.18	.19	.20	.20	.21	.23	.24	.25	.27	.29
64	-----	.22	.23	.24	.25	.26	.27	.29	.31	.32	.34	.37	.39
65	-----	.28	.29	.30	.32	.33	.34	.36	.39	.41	.43	.46	.49
66	-----	.34	.35	.36	.38	.40	.42	.44	.47	.50	.52	.56	.59
67	-----	.41	.42	.43	.45	.47	.50	.52	.55	.58	.61	.65	.70
68	-----	.48	.48	.50	.52	.54	.57	.60	.64	.67	.71	.75	.80
69	-----	.55	.56	.57	.59	.62	.66	.68	.73	.76	.80	.85	.91
70	-----	.62	.63	.64	.67	.70	.74	.77	.81	.86	.90	.96	1.02
72	-----	.77	.78	.80	.83	.86	.90	.94	.99	1.04	1.10	1.16	1.23
74	-----	.93	.94	.96	1.00	1.03	1.09	1.13	1.18	1.25	1.32	1.39	1.46
76	-----	1.10	1.13	1.17	1.21	1.27	1.32	1.38	1.46	1.54	1.61	1.70	
78	-----	1.28	1.31	1.35	1.40	1.46	1.52	1.59	1.67	1.76	1.84	1.94	
80	-----	1.46	1.50	1.54	1.60	1.66	1.73	1.80	1.89	1.99	2.09	2.20	
82	-----	1.64	1.69	1.74	1.80	1.87	1.94	2.02	2.12	2.22	2.34	2.45	
84	-----	1.84	1.89	1.94	2.00	2.08	2.16	2.25	2.35	2.47	2.59	2.71	
86	-----	2.09	2.15	2.22	2.30	2.39	2.49	2.60	2.72	2.84	2.97		
88	-----	2.30	2.37	2.44	2.53	2.62	2.73	2.85	2.98	3.10	3.23		
90	-----	2.52	2.59	2.66	2.76	2.86	2.98	3.11	3.24	3.36	3.50		
92	-----	2.74	2.82	2.89	3.00	3.11	3.24	3.37	3.51	3.64	3.78		
94	-----	2.97	3.04	3.12	3.24	3.36	3.50	3.63	3.78	3.92	4.07		
96	-----	3.28	3.36	3.49	3.62	3.76	3.90	4.05	4.20	4.36			
98	-----	3.52	3.60	3.74	3.88	4.03	4.17	4.32	4.50	4.66			
100	-----	3.76	3.85	4.00	4.15	4.30	4.45	4.60	4.78	4.95			

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)—Continued

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume											
	13	14	15	16	17	18	19	20	21	22	23	24
	Add to observed per cent alcohol											
50	0.90	0.99	1.09	1.19	1.30	1.41	1.52	1.62	1.72	1.82	1.90	1.98
51	.82	.90	.99	1.08	1.18	1.28	1.38	1.47	1.56	1.64	1.71	1.79
52	.74	.80	.89	.98	1.06	1.14	1.23	1.31	1.38	1.46	1.52	1.68
53	.65	.71	.78	.85	.94	1.00	1.08	1.16	1.21	1.28	1.34	1.39
54	.57	.62	.68	.74	.81	.86	.94	.99	1.04	1.10	1.15	1.20
55	.48	.52	.57	.62	.68	.72	.78	.83	.87	.92	.96	1.00
56	.38	.42	.46	.49	.54	.58	.63	.67	.69	.74	.77	.80
57	.29	.32	.35	.37	.40	.44	.47	.51	.53	.56	.58	.60
58	.19	.21	.23	.24	.26	.29	.32	.34	.35	.38	.40	.40
59	.10	.11	.12	.12	.13	.14	.16	.17	.18	.19	.20	.20
	Subtract from observed per cent alcohol											
	61	62	63	64	65	66	67	68	69	70	72	74
	76	78	80	82	84	86	88	90	92	94	96	98
61	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.18
62	.21	.22	.24	.26	.27	.29	.30	.32	.34	.36	.37	.38
63	.31	.32	.35	.38	.41	.44	.46	.49	.51	.53	.55	.56
64	.42	.44	.48	.52	.54	.58	.62	.66	.68	.71	.74	.77
65	.52	.55	.60	.65	.68	.73	.78	.82	.85	.90	.92	.96
66	.63	.66	.71	.77	.82	.88	.94	.98	1.02	1.07	1.11	1.16
67	.74	.78	.84	.90	.96	1.03	1.10	1.15	1.20	1.25	1.30	1.35
68	.85	.91	.97	1.03	1.10	1.18	1.26	1.33	1.38	1.44	1.49	1.54
69	.97	1.02	1.10	1.17	1.25	1.33	1.42	1.48	1.54	1.61	1.66	1.72
70	1.08	1.14	1.23	1.31	1.40	1.49	1.58	1.65	1.72	1.78	1.84	1.91
72	1.31	1.39	1.50	1.60	1.70	1.80	1.90	2.00	2.06	2.13	2.20	2.27
74	1.55	1.65	1.76	1.88	1.99	2.10	2.22	2.32	2.41	2.48	2.56	2.65
76	1.80	1.91	2.03	2.16	2.28	2.41	2.54	2.65	2.76	2.84	2.93	3.03
78	2.05	2.17	2.30	2.44	2.58	2.72	2.86	2.98	3.10	3.20	3.30	3.40
80	2.31	2.44	2.58	2.72	2.87	3.02	3.17	3.33	3.45	3.56	3.67	3.78
82	2.57	2.71	2.86	3.00	3.16	3.33	3.50	3.66	3.79	3.92	4.04	4.18
84	2.84	2.98	3.13	3.29	3.46	3.63	3.81	4.00	4.14	4.28	4.42	4.56
86	3.11	3.26	3.41	3.58	3.76	3.94	4.13	4.33	4.49	4.65	4.80	4.94
88	3.38	3.54	3.70	3.88	4.07	4.26	4.46	4.67	4.84	5.00	5.17	5.32
90	3.66	3.83	4.00	4.18	4.38	4.58	4.78	5.01	5.19	5.36	5.53	5.69
92	3.94	4.11	4.29	4.48	4.69	4.90	5.12	5.35	5.54	5.72	5.90	6.07
94	4.23	4.40	4.58	4.79	5.00	5.22	5.46	5.69	5.89	6.08	6.28	6.45
96	4.53	4.69	4.87	5.10	5.32	5.55	5.80	6.03	6.24	6.44	6.64	6.82
98	4.83	5.00	5.18	5.41	5.64	5.88	6.13	6.38	6.60	6.80	7.02	7.20
100	5.13	5.30	5.49	5.72	5.95	6.21	6.46	6.72	6.95	7.17	7.40	7.59

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)—Continued

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume										
	25	26	27	28	29	30	31	32	33	34	35
	Add to observed per cent alcohol										
50	2.06	2.12	2.18	2.24	2.28	2.31	2.32	2.32	2.32	2.31	2.29
51	1.85	1.90	1.96	2.02	2.05	2.08	2.10	2.09	2.09	2.08	2.07
52	1.64	1.69	1.74	1.78	1.82	1.84	1.85	1.86	1.86	1.85	1.84
53	1.44	1.48	1.52	1.56	1.58	1.60	1.61	1.62	1.63	1.62	1.61
54	1.24	1.27	1.30	1.34	1.36	1.36	1.38	1.39	1.40	1.38	1.38
55	1.03	1.06	1.08	1.10	1.12	1.13	1.14	1.15	1.16	1.15	1.15
56	.82	.85	.87	.89	.90	.90	.91	.92	.92	.92	.92
57	.62	.64	.65	.66	.67	.67	.68	.69	.70	.69	.69
58	.41	.42	.43	.44	.44	.44	.45	.46	.46	.46	.46
59	.21	.21	.21	.22	.22	.22	.22	.22	.23	.23	.23
Subtract from observed per cent alcohol											
61	0.19	0.20	0.20	0.21	0.22	0.23	0.23	0.23	0.23	0.23	0.23
62	.39	.40	.41	.42	.44	.46	.46	.46	.46	.46	.46
63	.59	.60	.62	.64	.66	.68	.68	.68	.68	.68	.68
64	.79	.80	.83	.86	.88	.91	.91	.91	.91	.91	.91
65	.99	1.00	1.04	1.08	1.10	1.12	1.13	1.13	1.14	1.14	1.14
66	1.19	1.21	1.25	1.30	1.32	1.35	1.36	1.36	1.36	1.36	1.36
67	1.39	1.41	1.45	1.50	1.54	1.57	1.58	1.59	1.60	1.60	1.60
68	1.58	1.64	1.68	1.72	1.76	1.79	1.80	1.81	1.82	1.82	1.82
69	1.77	1.82	1.86	1.91	1.96	2.00	2.02	2.03	2.04	2.04	2.04
70	1.97	2.02	2.08	2.12	2.18	2.22	2.24	2.26	2.27	2.27	2.27
72	2.36	2.42	2.48	2.54	2.60	2.66	2.68	2.70	2.71	2.72	2.72
74	2.74	2.81	2.88	2.96	3.04	3.10	3.12	3.15	3.16	3.18	3.18
76	3.14	3.21	3.30	3.38	3.46	3.52	3.56	3.58	3.60	3.63	3.64
78	3.51	3.61	3.70	3.78	3.86	3.95	3.99	4.03	4.06	4.08	4.09
80	3.90	4.00	4.10	4.19	4.28	4.37	4.42	4.48	4.51	4.53	4.54
82	4.29	4.40	4.50	4.60	4.70	4.80	4.86	4.91	4.95	4.98	5.00
84	4.68	4.80	4.91	5.02	5.12	5.24	5.30	5.35	5.40	5.42	5.44
86	5.07	5.20	5.32	5.44	5.54	5.64	5.72	5.79	5.84	5.88	5.90
88	5.46	5.60	5.72	5.84	5.95	6.06	6.14	6.20	6.26	6.31	6.34
90	5.84	5.98	6.12	6.24	6.36	6.46	6.55	6.62	6.68	6.74	6.78
92	6.23	6.38	6.52	6.66	6.77	6.87	6.97	7.04	7.12	7.18	7.22
94	6.62	6.78	6.93	7.06	7.18	7.29	7.38	7.47	7.54	7.61	7.66
96	7.00	7.17	7.32	7.46	7.60	7.71	7.82	7.90	7.98	8.06	8.10
98	7.40	7.57	7.72	7.87	8.01	8.12	8.24	8.33	8.42	8.50	8.54
100	7.78	7.96	8.12	8.28	8.42	8.55	8.68	8.76	8.84	8.93	9.00

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)—Continued

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume										
	36	37	38	39	40	45	50	55	60	65	70
	Add to observed per cent alcohol										
50	2.28	2.27	2.26	2.25	2.24	2.14	2.04	1.98	1.90	1.85	1.78
51	2.06	2.04	2.03	2.03	2.02	1.91	1.84	1.78	1.71	1.66	1.60
52	1.82	1.80	1.80	1.80	1.79	1.71	1.64	1.58	1.52	1.47	1.42
53	1.60	1.58	1.58	1.58	1.56	1.50	1.44	1.38	1.33	1.29	1.25
54	1.37	1.36	1.36	1.36	1.34	1.28	1.23	1.19	1.14	1.11	1.08
55	1.14	1.13	1.13	1.13	1.11	1.06	1.02	.99	.95	.92	.90
56	.91	.90	.90	.90	.89	.85	.81	.79	.76	.74	.72
57	.68	.67	.68	.68	.67	.64	.61	.59	.57	.55	.54
58	.46	.46	.46	.46	.45	.42	.40	.39	.39	.38	.36
59	.23	.23	.23	.23	.23	.21	.20	.20	.19	.18	.18
	Subtract from observed per cent alcohol										
	61	62	63	64	65	66	67	68	69	70	
	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.20	0.20	0.18	0.18
61	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.20	0.20	0.18	0.18
62	.46	.46	.46	.46	.45	.44	.42	.40	.39	.38	.36
63	.68	.68	.68	.68	.68	.66	.62	.60	.58	.56	.54
64	.92	.92	.91	.90	.90	.87	.84	.81	.78	.75	.72
65	1.14	1.14	1.13	1.12	1.12	1.09	1.05	1.01	.97	.94	.90
66	1.37	1.36	1.36	1.35	1.34	1.30	1.25	1.21	1.17	1.13	1.09
67	1.60	1.60	1.60	1.58	1.56	1.52	1.46	1.41	1.37	1.32	1.27
68	1.82	1.82	1.81	1.80	1.79	1.74	1.66	1.61	1.55	1.50	1.45
69	2.04	2.03	2.03	2.03	2.01	1.96	1.88	1.81	1.75	1.69	1.63
70	2.27	2.27	2.26	2.25	2.24	2.17	2.09	2.02	1.95	1.88	1.82
72	2.72	2.72	2.72	2.70	2.68	2.61	2.51	2.42	2.34	2.26	2.18
74	3.18	3.17	3.17	3.16	3.14	3.04	2.93	2.83	2.73	2.65	2.56
76	3.63	3.62	3.62	3.60	3.58	3.47	3.35	3.24	3.13	3.03	2.93
78	4.09	4.08	4.07	4.06	4.02	3.92	3.78	3.64	3.53	3.42	3.30
80	4.54	4.53	4.52	4.50	4.48	4.36	4.20	4.05	3.93	3.80	3.68
82	5.00	4.98	4.98	4.96	4.94	4.81	4.63	4.47	4.33	4.19	4.06
84	5.45	5.44	5.43	5.40	5.38	5.25	5.06	4.88	4.73	4.58	4.44
86	5.90	5.89	5.88	5.86	5.84	5.70	5.49	5.30	5.14	4.98	4.82
88	6.35	6.34	6.33	6.31	6.29	6.14	5.92	5.72	5.54	5.37	5.20
90	6.80	6.80	6.78	6.76	6.73	6.58	6.36	6.14	5.95	5.76	5.59
92	7.25	7.25	7.22	7.20	7.18	7.03	6.80	6.56	6.36	6.16	5.98
94	7.70	7.70	7.67	7.66	7.63	7.48	7.24	6.98	6.77	6.56	6.37
96	8.14	8.15	8.12	8.11	8.08	7.92	7.68	7.40	7.19	6.96	6.76
98	8.58	8.60	8.58	8.56	8.54	8.36	8.11	7.82	7.60	7.36	7.15
100	9.03	9.04	9.03	9.01	8.98	8.81	8.45	8.25	8.02	7.76	7.54

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)—Continued

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume									
	75	80	81	82	83	84	85	86	87	88
	Add to observed per cent alcohol									
50	1.71	1.63	1.62	1.60	1.58	1.56	1.53	1.51	1.48	1.46
51	1.54	1.47	1.46	1.44	1.42	1.40	1.38	1.36	1.33	1.31
52	1.36	1.30	1.30	1.28	1.26	1.24	1.22	1.20	1.18	1.16
53	1.20	1.15	1.14	1.12	1.11	1.09	1.07	1.06	1.04	1.02
54	1.04	.98	.98	.96	.95	.94	.92	.91	.89	.88
55	.87	.82	.81	.80	.79	.78	.76	.75	.74	.72
56	.70	.66	.65	.64	.63	.62	.61	.60	.59	.57
57	.53	.49	.49	.48	.48	.47	.46	.45	.45	.43
58	.34	.32	.32	.32	.31	.30	.30	.30	.30	.28
59	.17	.16	.16	.16	.16	.15	.15	.15	.15	.14
Subtract from observed per cent alcohol										
61	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.15
62	.34	.34	.34	.32	.32	.32	.32	.31	.31	.30
63	.52	.50	.50	.48	.48	.48	.48	.47	.46	.44
64	.70	.68	.66	.65	.65	.64	.63	.62	.61	.60
65	.86	.84	.82	.82	.81	.80	.79	.78	.77	.76
66	1.05	1.00	.99	.98	.97	.96	.94	.93	.92	.90
67	1.22	1.17	1.16	1.14	1.13	1.12	1.10	1.09	1.08	1.06
68	1.40	1.33	1.32	1.31	1.29	1.28	1.26	1.24	1.22	1.20
69	1.57	1.50	1.49	1.47	1.46	1.44	1.42	1.40	1.38	1.36
70	1.75	1.68	1.66	1.64	1.62	1.60	1.58	1.56	1.54	1.51
72	2.10	2.02	2.00	1.97	1.95	1.93	1.90	1.88	1.85	1.82
74	2.46	2.36	2.34	2.30	2.28	2.26	2.24	2.20	2.17	2.13
76	2.81	2.70	2.68	2.64	2.61	2.59	2.56	2.52	2.48	2.44
78	3.18	3.04	3.02	2.98	2.94	2.92	2.88	2.84	2.80	2.76
80	3.54	3.38	3.36	3.32	3.28	3.26	3.22	3.17	3.13	3.08
82	3.90	3.72	3.71	3.66	3.62	3.59	3.54	3.50	3.45	3.40
84	4.27	4.08	4.05	4.00	3.96	3.92	3.86	3.83	3.77	3.72
86	4.64	4.43	4.39	4.35	4.30	4.26	4.21	4.16	4.10	4.04
88	5.00	4.78	4.75	4.70	4.65	4.60	4.55	4.50	4.44	4.37
90	5.37	5.14	5.10	5.06	5.00	4.95	4.88	4.83	4.77	4.70
92	5.75	5.50	5.46	5.42	5.36	5.30	5.23	5.18	5.10	5.03
94	6.12	5.86	5.81	5.76	5.70	5.64	5.58	5.51	5.44	5.36
96	6.50	6.23	6.17	6.12	6.06	5.99	5.92	5.86	5.78	5.69
98	6.88	6.60	6.50	6.45	6.41	6.34	6.26	6.20	6.11	6.02
100	7.26	6.96	6.89	6.84	6.76	6.70	6.61	6.54	6.44	6.36

TABLE 4.—Temperature corrections to readings of alcoholometers (standard at 60° F.)—Continued

Observed temperature in degrees Fahrenheit	Observed per cent alcohol by volume										
	90	91	92	93	94	95	96	97	98	99	100
	Add to observed per cent alcohol										
50	1.39	1.36	1.32	1.27	1.22	1.17	1.12	1.06	0.99	0.93	-----
51	1.25	1.22	1.18	1.14	1.10	1.05	1.01	.95	.89	.84	-----
52	1.12	1.09	1.05	1.02	.98	.94	.90	.85	.79	.74	-----
53	.98	.95	.93	.90	.86	.83	.79	.74	.70	.65	-----
54	.84	.82	.80	.77	.74	.72	.68	.64	.60	.56	-----
55	.70	.69	.66	.64	.62	.60	.57	.53	.50	.47	-----
56	.56	.55	.53	.52	.49	.48	.45	.43	.40	.38	-----
57	.42	.41	.40	.39	.37	.36	.34	.32	.30	.29	-----
58	.28	.27	.26	.26	.24	.24	.23	.21	.20	.19	-----
59	.14	.14	.13	.13	.12	.12	.12	.11	.10	.10	-----
	Subtract from observed per cent alcohol										
61	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.10	0.09
62	.29	.28	.27	.26	.25	.24	.23	.22	.21	.19	.18
63	.43	.42	.41	.39	.38	.36	.35	.33	.31	.29	.27
64	.58	.55	.54	.52	.51	.49	.46	.44	.41	.39	.36
65	.72	.70	.68	.66	.64	.61	.58	.55	.52	.49	.46
66	.86	.84	.82	.79	.76	.73	.70	.67	.63	.59	.55
67	1.00	.98	.96	.93	.90	.86	.82	.78	.74	.70	.64
68	1.15	1.12	1.09	1.06	1.02	.98	.94	.90	.85	.80	.74
69	1.30	1.26	1.23	1.20	1.16	1.10	1.06	1.02	.96	.90	.84
70	1.45	1.41	1.37	1.34	1.30	1.23	1.19	1.14	1.07	1.00	.94
72	1.74	1.70	1.65	1.61	1.55	1.49	1.43	1.37	1.30	1.22	1.13
74	2.05	2.00	1.94	1.89	1.82	1.75	1.69	1.61	1.53	1.43	1.33
76	2.35	2.29	2.23	2.17	2.09	2.01	1.94	1.85	1.76	1.65	1.53
78	2.65	2.59	2.52	2.46	2.36	2.28	2.20	2.10	2.00	1.87	1.73
80	2.95	2.89	2.82	2.74	2.64	2.56	2.46	2.35	2.24	2.09	1.93
82	3.25	3.20	3.12	3.03	2.92	2.84	2.72	2.60	2.48	2.32	2.14
84	3.57	3.50	3.39	3.32	3.21	3.10	2.96	2.86	2.73	2.56	2.36
86	3.89	3.80	3.72	3.62	3.51	3.38	3.26	3.13	2.98	2.80	2.58
88	4.20	4.12	4.02	3.91	3.80	3.66	3.54	3.39	3.24	3.06	2.81
90	4.52	4.42	4.32	4.20	4.08	3.94	3.81	3.66	3.50	3.30	3.03
92	4.84	4.74	4.62	4.50	4.38	4.23	4.10	3.93	3.76	3.55	3.26
94	5.16	5.05	4.94	4.80	4.67	4.52	4.38	4.20	4.02	3.80	3.50
96	5.49	5.39	5.25	5.11	4.97	4.82	4.67	4.48	4.29	4.06	3.73
98	5.82	5.70	5.56	5.42	5.27	5.12	4.95	4.76	4.55	4.31	3.96
100	6.15	6.02	5.88	5.74	5.58	5.42	5.24	5.04	4.82	4.56	4.21

105396°—24†—2

TABLE 5.—Percentages by volume at 60° F., corresponding to various percentages by weight in mixtures of ethyl alcohol and water

Per cent alcohol by weight	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
0	0.000	0.126	0.252	0.378	0.504	0.630	0.755	0.881	1.007	1.132
1	1.257	1.382	1.508	1.633	1.759	1.884	2.009	2.134	2.260	2.385
2	2.510	2.635	2.760	2.885	3.010	3.135	3.260	3.384	3.509	3.633
3	3.758	3.883	4.007	4.132	4.256	4.381	4.505	4.629	4.754	4.878
4	5.002	5.126	5.250	5.374	5.499	5.623	5.747	5.871	5.995	6.119
5	6.243	6.367	6.491	6.614	6.738	6.862	6.985	7.109	7.232	7.356
6	7.479	7.602	7.726	7.849	7.972	8.096	8.219	8.342	8.466	8.589
7	8.712	8.835	8.958	9.081	9.205	9.328	9.451	9.574	9.697	9.820
8	9.943	10.066	10.189	10.311	10.434	10.557	10.679	10.802	10.925	11.047
9	11.169	11.292	11.414	11.536	11.659	11.781	11.904	12.026	12.149	12.271
10	12.393	12.515	12.637	12.760	12.882	13.004	13.126	13.248	13.370	13.492
11	13.613	13.735	13.857	13.979	14.101	14.223	14.345	14.466	14.588	14.710
12	14.832	14.954	15.075	15.197	15.319	15.440	15.562	15.683	15.805	15.926
13	16.047	16.168	16.290	16.411	16.532	16.654	16.775	16.896	17.017	17.138
14	17.259	17.380	17.501	17.622	17.743	17.864	17.985	18.106	18.227	18.348
15	18.469	18.590	18.711	18.832	18.952	19.073	19.194	19.315	19.435	19.556
16	19.676	19.797	19.917	20.038	20.158	20.279	20.399	20.519	20.640	20.760
17	20.880	21.000	21.120	21.241	21.361	21.481	21.601	21.721	21.841	21.961
18	22.081	22.201	22.321	22.441	22.561	22.680	22.800	22.919	23.039	23.159
19	23.278	23.398	23.517	23.636	23.756	23.876	23.995	24.114	24.234	24.353
20	24.472	24.591	24.710	24.829	24.949	25.068	25.187	25.305	25.424	25.543
21	25.662	25.781	25.900	26.018	26.137	26.256	26.375	26.493	26.612	26.730
22	26.849	26.968	27.086	27.204	27.323	27.441	27.559	27.677	27.796	27.914
23	28.032	28.150	28.268	28.386	28.504	28.622	28.740	28.858	28.976	29.093
24	29.210	29.328	29.446	29.563	29.681	29.799	29.917	30.035	30.152	30.270
25	30.388	30.505	30.622	30.739	30.855	30.972	31.089	31.205	31.322	31.438
26	31.555	31.672	31.788	31.905	32.021	32.138	32.254	32.370	32.487	32.603
27	32.719	32.835	32.951	33.068	33.184	33.300	33.416	33.532	33.647	33.763
28	33.879	33.995	34.111	34.227	34.342	34.458	34.573	34.688	34.803	34.918
29	35.033	35.148	35.263	35.378	35.493	35.608	35.723	35.838	35.952	36.066
30	36.181	36.296	36.410	36.524	36.639	36.753	36.867	36.981	37.095	37.209
31	37.323	37.437	37.551	37.664	37.778	37.892	38.005	38.119	38.232	38.346
32	38.459	38.572	38.686	38.799	38.912	39.025	39.138	39.251	39.364	39.477
33	39.590	39.703	39.816	39.928	40.041	40.154	40.266	40.379	40.492	40.604
34	40.716	40.828	40.940	41.052	41.163	41.275	41.386	41.498	41.609	41.721
35	41.832	41.943	42.055	42.166	42.277	42.389	42.500	42.611	42.722	42.833
36	42.944	43.055	43.165	43.276	43.387	43.498	43.608	43.719	43.829	43.939
37	44.050	44.160	44.270	44.381	44.490	44.600	44.710	44.820	44.930	45.039
38	45.149	45.259	45.368	45.478	45.587	45.696	45.806	45.915	46.024	46.133
39	46.242	46.351	46.460	46.569	46.678	46.786	46.895	47.003	47.112	47.220
40	47.328	47.436	47.544	47.652	47.760	47.868	47.976	48.084	48.192	48.299
41	48.407	48.515	48.622	48.730	48.837	48.945	49.052	49.159	49.266	49.373
42	49.480	49.587	49.694	49.801	49.907	50.014	50.120	50.226	50.333	50.439
43	50.545	50.651	50.757	50.864	50.970	51.076	51.182	51.288	51.394	51.499
44	51.605	51.711	51.816	51.922	52.027	52.132	52.238	52.343	52.448	52.553
45	52.658	52.763	52.868	52.973	53.078	53.182	53.287	53.392	53.496	53.601
46	53.705	53.809	53.914	54.018	54.122	54.226	54.330	54.434	54.538	54.642
47	54.746	54.850	54.954	55.057	55.161	55.264	55.368	55.471	55.574	55.677
48	55.780	55.883	55.986	56.089	56.192	56.295	56.398	56.500	56.603	56.706
49	56.808	56.910	57.013	57.116	57.218	57.320	57.422	57.522	57.626	57.728
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743

TABLE 5.—Percentages by volume at 60° F., corresponding to various percentages by weight in mixtures of ethyl alcohol and water—Continued

Per cent alcohol by weight	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
50	57.830	57.932	58.034	58.135	58.237	58.338	58.440	58.541	58.642	58.743
51	58.844	58.945	59.046	59.147	59.248	59.349	59.450	59.550	59.651	59.752
52	59.852	59.952	60.053	60.154	60.254	60.354	60.454	60.554	60.654	60.754
53	60.854	60.954	61.054	61.154	61.254	61.353	61.453	61.552	61.652	61.751
54	61.850	61.949	62.048	62.147	62.246	62.344	62.443	62.542	62.640	62.738
55	62.837	62.936	63.034	63.132	63.231	63.329	63.427	63.526	63.624	63.722
56	63.820	63.918	64.016	64.114	64.212	64.310	64.408	64.505	64.603	64.701
57	64.798	64.895	64.993	65.090	65.188	65.285	65.382	65.479	65.575	65.672
58	65.768	65.865	65.961	66.058	66.154	66.251	66.347	66.444	66.540	66.636
59	66.732	66.828	66.924	67.020	67.116	67.212	67.308	67.404	67.499	67.595
60	67.690	67.785	67.881	67.976	68.071	68.166	68.261	68.356	68.451	68.546
61	68.641	68.736	68.831	68.925	69.020	69.115	69.209	69.304	69.398	69.492
62	69.596	69.690	69.774	69.868	69.962	70.056	70.149	70.243	70.336	70.430
63	70.523	70.616	70.710	70.803	70.897	70.990	71.083	71.176	71.269	71.362
64	71.455	71.548	71.641	71.733	71.826	71.918	72.011	72.103	72.196	72.288
65	72.380	72.472	72.564	72.656	72.748	72.840	72.932	73.024	73.116	73.207
66	73.299	73.391	73.482	73.574	73.665	73.756	73.847	73.938	74.029	74.120
67	74.211	74.302	74.393	74.484	74.575	74.665	74.756	74.846	74.937	75.027
68	75.117	75.207	75.297	75.387	75.477	75.567	75.657	75.747	75.837	75.926
69	76.016	76.106	76.195	76.285	76.374	76.464	76.553	76.642	76.731	76.820
70	76.909	76.998	77.087	77.176	77.264	77.353	77.441	77.529	77.618	77.706
71	77.794	77.882	77.970	78.058	78.146	78.234	78.322	78.410	78.497	78.584
72	78.672	78.760	78.847	78.934	79.022	79.109	79.196	79.283	79.370	79.457
73	79.544	79.631	79.718	79.805	79.892	79.978	80.065	80.151	80.238	80.324
74	80.410	80.496	80.582	80.668	80.754	80.840	80.926	81.012	81.098	81.183
75	81.269	81.355	81.440	81.526	81.611	81.696	81.781	81.866	81.951	82.036
76	82.121	82.206	82.291	82.376	82.461	82.545	82.630	82.714	82.799	82.883
77	82.967	83.051	83.135	83.219	83.303	83.387	83.471	83.555	83.638	83.722
78	83.805	83.888	83.972	84.055	84.138	84.221	84.304	84.387	84.470	84.553
79	84.636	84.719	84.801	84.884	84.966	85.049	85.131	85.213	85.295	85.377
80	85.459	85.541	85.623	85.705	85.787	85.868	85.950	86.031	86.113	86.194
81	86.275	86.356	86.437	86.518	86.599	86.680	86.761	86.842	86.922	87.002
82	87.083	87.164	87.244	87.324	87.405	87.485	87.565	87.645	87.725	87.805
83	87.885	87.965	88.045	88.124	88.204	88.283	88.362	88.441	88.520	88.599
84	88.678	88.757	88.836	88.915	88.994	89.072	89.151	89.229	89.308	89.386
85	89.464	89.542	89.620	89.698	89.776	89.854	89.932	90.009	90.086	90.163
86	90.240	90.317	90.394	90.471	90.548	90.625	90.702	90.779	90.855	90.932
87	91.008	91.084	91.161	91.237	91.313	91.388	91.464	91.540	91.615	91.691
88	91.766	91.841	91.917	91.992	92.068	92.143	92.218	92.293	92.367	92.442
89	92.517	92.591	92.666	92.740	92.814	92.888	92.962	93.035	93.108	93.181
90	93.254	93.327	93.400	93.473	93.546	93.619	93.692	93.764	93.837	93.910
91	93.982	94.054	94.126	94.198	94.270	94.342	94.414	94.486	94.557	94.629
92	94.700	94.771	94.842	94.913	94.984	95.055	95.126	95.196	95.267	95.337
93	95.407	95.477	95.547	95.617	95.687	95.757	95.826	95.896	95.965	96.034
94	96.103	96.172	96.241	96.310	96.378	96.447	96.515	96.583	96.652	96.720
95	96.787	96.855	96.922	96.990	97.057	97.125	97.192	97.259	97.326	97.392
96	97.459	97.526	97.592	97.658	97.724	97.790	97.856	97.921	97.987	98.052
97	98.117	98.182	98.247	98.312	98.376	98.440	98.505	98.569	98.633	98.696
98	98.759	98.822	98.886	98.949	99.012	99.075	99.137	99.200	99.262	99.324
99	99.386	99.448	99.510	99.572	99.633	99.695	99.756	99.817	99.878	99.939
100	100.000									

TABLE 6.—Percentages by weight, corresponding to various percentages by volume at 60° F. in mixtures of ethyl alcohol and water

Per cent alcohol by volume at 60° F.	Per cent alcohol by weight	Differences	Per cent alcohol by volume at 60° F.	Per cent alcohol by weight	Differences
0	0.000	-----	50	42.487	-----
1	0.795	0.795	51	43.428	0.941
2	1.593	.798	52	44.374	.946
3	2.392	.799	53	45.326	.952
4	3.194	.802	54	46.283	.957
		.804			.962
5	3.998		55	47.245	
6	4.804	.806	56	48.214	.969
7	5.612	.808	57	49.187	.973
8	6.422	.810	58	50.167	.980
9	7.234	.812	59	51.154	.987
		.813			.993
10	8.047		60	52.147	
11	8.862	.815	61	53.146	.999
12	9.679	.817	62	54.152	1.006
13	10.497	.818	63	55.165	1.013
14	11.317	.820	64	56.184	1.019
		.821			1.024
15	12.138		65	57.208	
16	12.961	.823	66	58.241	1.033
17	13.786	.825	67	59.279	1.038
18	14.612	.826	68	60.325	1.046
19	15.440	.828	69	61.379	1.054
		.829			1.062
20	16.269		70	62.441	
21	17.100	.831	71	63.511	1.070
22	17.933	.833	72	64.588	1.077
23	18.768	.835	73	65.674	1.086
24	19.604	.836	74	66.768	1.094
		.839			1.102
25	20.443		75	67.870	
26	21.285	.842	76	68.982	1.112
27	22.127	.842	77	70.102	1.120
28	22.973	.846	78	71.234	1.132
29	23.820	.847	79	72.375	1.141
		.850			1.151
30	24.670		80	73.526	
31	25.524	.854	81	74.686	1.160
32	26.382	.858	82	75.858	1.172
33	27.242	.860	83	77.039	1.181
34	28.104	.862	84	78.233	1.194
		.867			1.208
35	28.971		85	79.441	
36	29.842	.871	86	80.662	1.221
37	30.717	.875	87	81.897	1.235
38	31.596	.879	88	83.144	1.247
39	32.478	.882	89	84.408	1.264
		.886			1.281
40	33.364		90	85.689	
41	34.254	.890	91	86.989	1.300
42	35.150	.896	92	88.310	1.321
43	36.050	.900	93	89.652	1.342
44	36.955	.905	94	91.025	1.373
		.910			1.398
45	37.865		95	92.423	
46	38.778	.913	96	93.851	1.428
47	39.697	.919	97	95.315	1.464
48	40.622	.925	98	96.820	1.505
49	41.551	.929	99	98.381	1.561
		.936			1.619
50	42.487	-----	100	100.000	-----

TABLE 7.—Temperature corrections to readings of alcoholometers (standard at 80° C.)

[This table is calculated from the same data on the thermal expansion of ethyl alcohol as that from which Tables 1, 2, 3, 4, 5, and 6 are calculated. The hydrometer is assumed to be of Jena 18° glass.]

Observed temperature in degrees centigrade	Observed per cent alcohol by weight																					
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
Add to observed per cent alcohol																						
10	0.67	0.91	1.47	2.43	3.18	3.55	3.59	3.55	3.49	3.47	3.45	3.45	3.45	3.45	3.45	3.43	3.42	3.36	3.26	3.08	2.86	2.58
11	.68	.84	1.35	2.20	2.84	3.19	3.24	3.20	3.14	3.11	3.10	3.10	3.10	3.10	3.10	3.09	3.08	3.03	2.93	2.78	2.58	2.31
12	.69	.86	1.32	2.15	2.80	3.15	3.20	3.15	3.09	3.07	3.06	3.06	3.06	3.06	3.06	3.05	3.04	2.99	2.89	2.76	2.56	2.30
13	.70	.88	1.29	2.10	2.75	3.10	3.15	3.10	3.04	3.02	3.01	3.01	3.01	3.01	3.01	3.00	2.99	2.94	2.85	2.74	2.54	2.28
14	.71	.90	1.26	2.05	2.70	3.05	3.10	3.05	2.99	2.97	2.96	2.96	2.96	2.96	2.96	2.95	2.94	2.89	2.81	2.72	2.52	2.26
15	.72	.91	1.23	2.00	2.65	3.00	3.05	3.00	2.94	2.92	2.91	2.91	2.91	2.91	2.91	2.90	2.89	2.84	2.77	2.68	2.48	2.22
16	.73	.92	1.20	1.95	2.60	2.95	3.00	2.95	2.89	2.87	2.86	2.86	2.86	2.86	2.86	2.85	2.84	2.79	2.72	2.64	2.44	2.18
17	.74	.93	1.17	1.90	2.55	2.90	2.95	2.90	2.84	2.82	2.81	2.81	2.81	2.81	2.81	2.80	2.79	2.74	2.68	2.60	2.40	2.14
18	.75	.94	1.14	1.85	2.50	2.85	2.90	2.85	2.79	2.77	2.76	2.76	2.76	2.76	2.76	2.75	2.74	2.69	2.64	2.56	2.36	2.10
19	.76	.95	1.11	1.80	2.45	2.80	2.85	2.80	2.74	2.72	2.71	2.71	2.71	2.71	2.71	2.70	2.69	2.64	2.59	2.51	2.31	2.05
Subtract from observed per cent alcohol																						
21	0.13	0.17	0.24	0.33	0.42	0.50	0.57	0.63	0.68	0.72	0.75	0.77	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87
22	.26	.34	.45	.56	.66	.74	.81	.87	.92	.96	.99	1.01	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
23	.39	.52	.67	.81	.94	1.06	1.17	1.27	1.35	1.41	1.45	1.48	1.50	1.51	1.52	1.53	1.54	1.55	1.56	1.57	1.58	1.59
24	.53	.70	.88	1.08	1.29	1.50	1.67	1.83	1.97	2.09	2.19	2.27	2.33	2.37	2.40	2.42	2.44	2.45	2.46	2.47	2.48	2.49
25	.67	.89	1.23	1.59	1.96	2.32	2.65	2.97	3.27	3.54	3.78	3.99	4.17	4.32	4.45	4.56	4.65	4.72	4.78	4.83	4.87	4.90
26	.81	1.08	1.46	1.87	2.28	2.67	3.02	3.35	3.64	3.89	4.11	4.30	4.46	4.60	4.72	4.82	4.90	4.96	5.01	5.05	5.08	5.11
27	.96	1.27	1.68	2.13	2.57	2.98	3.35	3.68	3.97	4.21	4.41	4.58	4.73	4.86	4.97	5.06	5.13	5.19	5.23	5.26	5.28	5.30
28	1.12	1.46	1.90	2.38	2.85	3.28	3.66	3.99	4.27	4.51	4.71	4.87	5.01	5.13	5.23	5.31	5.38	5.43	5.47	5.50	5.52	5.54
29	1.28	1.65	2.12	2.63	3.13	3.58	3.97	4.31	4.59	4.83	5.03	5.19	5.32	5.43	5.52	5.59	5.65	5.69	5.72	5.74	5.76	5.78
30	1.44	1.84	2.35	2.90	3.43	3.90	4.31	4.66	4.94	5.18	5.38	5.54	5.67	5.77	5.85	5.91	5.96	5.99	6.01	6.03	6.04	6.05
31	1.61	2.05	2.60	3.18	3.74	4.24	4.67	5.04	5.32	5.56	5.75	5.90	6.02	6.12	6.20	6.26	6.31	6.34	6.36	6.37	6.38	6.39
32	1.79	2.26	2.83	3.45	4.05	4.58	5.05	5.44	5.73	5.97	6.16	6.31	6.43	6.53	6.60	6.65	6.69	6.72	6.74	6.75	6.76	6.77
33	1.96	2.46	3.06	3.72	4.35	4.90	5.39	5.80	6.10	6.34	6.53	6.68	6.80	6.90	6.97	7.02	7.05	7.07	7.08	7.09	7.10	7.11
34	2.13	2.67	3.30	3.99	4.67	5.26	5.78	6.22	6.52	6.76	6.94	7.09	7.21	7.31	7.38	7.43	7.46	7.48	7.49	7.50	7.51	7.52
35	2.31	2.88	3.54	4.26	4.98	5.60	6.15	6.63	7.03	7.37	7.66	7.90	8.06	8.19	8.30	8.39	8.45	8.49	8.51	8.52	8.53	8.54
36	2.50	3.10	3.84	4.61	5.38	6.05	6.66	7.22	7.63	7.98	8.27	8.51	8.67	8.80	8.91	8.99	9.05	9.08	9.10	9.11	9.12	9.13
37	2.69	3.32	4.10	4.92	5.73	6.45	7.09	7.68	8.19	8.54	8.83	9.07	9.23	9.36	9.47	9.55	9.61	9.64	9.66	9.67	9.68	9.69
38	2.87	3.54	4.36	5.22	6.08	6.85	7.53	8.15	8.67	9.02	9.31	9.55	9.71	9.84	9.95	10.03	10.09	10.12	10.14	10.15	10.16	10.17
39	3.06	3.77	4.63	5.54	6.45	7.27	8.00	8.64	9.17	9.52	9.81	10.05	10.21	10.34	10.45	10.54	10.60	10.63	10.65	10.66	10.67	10.68
40	3.25	3.99	4.88	5.84	6.80	7.66	8.43	9.18	9.72	10.07	10.36	10.60	10.76	10.89	11.00	11.09	11.15	11.19	11.21	11.22	11.23	11.24

TABLE 8.—Density at 15° C. of mixtures (by weight) of methyl alcohol and water

[Calculated from the specific gravity determinations of Doroshevskii and Rozhdestvenskii at $\frac{15^\circ}{15^\circ}$ C.¹]

Per cent methyl alcohol by weight	D $\frac{15^\circ}{4^\circ}$ C.	Differences	Per cent methyl alcohol by weight	D $\frac{15^\circ}{4^\circ}$ C.	Differences
0	0.99913	0.00186	50	0.91852	0.00199
1	.99727	184	51	.91653	202
2	.99543	173	52	.91451	203
3	.99370	172	53	.91248	204
4	.99198	169	54	.91044	205
5	.99029	165	55	.90839	208
6	.98864	163	56	.90631	210
7	.98701	154	57	.90421	211
8	.98547	153	58	.90210	214
9	.98394	153	59	.89996	215
10	.98241	148	60	.89781	218
11	.98093	148	61	.89563	222
12	.97945	143	62	.89341	224
13	.97802	142	63	.89117	227
14	.97660	142	64	.88890	228
15	.97518	141	65	.88662	229
16	.97377	140	66	.88433	230
17	.97237	141	67	.88203	232
18	.97096	141	68	.87971	232
19	.96955	141	69	.87739	232
20	.96814	141	70	.87507	236
21	.96673	140	71	.87271	238
22	.96533	141	72	.87033	241
23	.96392	141	73	.86792	246
24	.96251	143	74	.86546	246
25	.96108	145	75	.86300	249
26	.95963	146	76	.86051	250
27	.95817	149	77	.85801	250
28	.95668	150	78	.85551	251
29	.95518	152	79	.85300	252
30	.95366	153	80	.85048	254
31	.95213	157	81	.84794	258
32	.95056	160	82	.84536	262
33	.94896	162	83	.84274	265
34	.94734	164	84	.84009	267
35	.94570	166	85	.83742	267
36	.94404	167	86	.83475	268
37	.94237	170	87	.83207	270
38	.94067	173	88	.82937	270
39	.93894	174	89	.82667	271
40	.93720	177	90	.82396	272
41	.93543	178	91	.82124	275
42	.93365	180	92	.81849	281
43	.93185	184	93	.81568	283
44	.93001	186	94	.81285	286
45	.92815	188	95	.80999	286
46	.92627	191	96	.80713	285
47	.92436	194	97	.80428	285
48	.92242	194	98	.80143	284
49	.92048	196	99	.79859	282
50	.91852	-----	100	.79577	-----

¹ J. Russ., Phys. Chem. Soc., 41, pp. 977-996; 1909.

TABLE 9.—*Specific gravity at $\frac{15^\circ}{15^\circ}$ C. of mixtures (by volume) of methyl alcohol and water*

[Calculated from the same data as Table 8]

Per cent methyl alcohol by volume at 15° C.	D $\frac{15^\circ}{15^\circ}$ C.	Differences	Per cent methyl alcohol by volume at 15° C.	D $\frac{15^\circ}{15^\circ}$ C.	Differences
0	1.00000	0.00149	50	0.93326	0.00171
1	.99851	148	51	.93155	173
2	.99703	143	52	.92982	176
3	.99550	138	53	.92806	180
4	.99422	139	54	.92626	183
5	.99283	137	55	.92443	187
6	.99146	135	56	.92256	189
7	.99011	134	57	.92067	190
8	.98877	131	58	.91877	195
9	.98746	125	59	.91682	199
10	.98621	125	60	.91483	201
11	.98496	126	61	.91282	203
12	.98370	123	62	.91079	206
13	.98247	122	63	.90873	210
14	.98125	122	64	.90663	213
15	.98003	119	65	.90450	216
16	.97884	118	66	.90234	220
17	.97766	118	67	.90014	224
18	.97648	118	68	.89790	229
19	.97530	117	69	.89561	234
20	.97413	118	70	.89327	239
21	.97295	118	71	.89088	244
22	.97177	119	72	.88844	248
23	.97058	119	73	.88596	250
24	.96939	119	74	.88346	254
25	.96820	120	75	.88092	256
26	.96700	120	76	.87836	258
27	.96580	121	77	.87578	266
28	.96459	121	78	.87312	272
29	.96338	122	79	.87040	280
30	.96216	125	80	.86760	286
31	.96091	125	81	.86474	294
32	.95966	128	82	.86180	297
33	.95838	130	83	.85883	301
34	.95708	132	84	.85582	306
35	.95576	133	85	.85276	309
36	.95443	135	86	.84967	321
37	.95308	138	87	.84646	332
38	.95170	141	88	.84314	343
39	.95029	143	89	.83971	348
40	.94886	145	90	.83623	354
41	.94741	148	91	.83269	362
42	.94593	150	92	.82907	369
43	.94443	152	93	.82538	375
44	.94291	155	94	.82163	391
45	.94136	157	95	.81772	409
46	.93979	159	96	.81363	421
47	.93820	163	97	.80942	428
48	.93657	164	98	.80514	432
49	.93493	167	99	.80082	435
50	.93326	-----	100	.79647	-----

TABLE 10.—Percentages by volume at 15° C. corresponding to various percentages by weight in mixtures of methyl alcohol and water

Per cent by weight.	Per cent by volume at 15° C.	Differences.	Per cent by weight.	Per cent by volume at 15° C.	Differences.
0	0.000	1.253	50	57.712	1.027
1	1.253	1.249	51	58.729	1.020
2	2.502	1.244	52	59.759	1.014
3	3.746	1.240	53	60.773	1.008
4	4.986	1.236	54	61.781	1.002
5	6.222	1.232	55	62.783	.995
6	7.454	1.228	56	63.778	.989
7	8.682	1.225	57	64.767	.983
8	9.907	1.221	58	65.750	.975
9	11.128	1.217	59	66.725	.968
10	12.345	1.214	60	67.693	.961
11	13.559	1.211	61	68.654	.953
12	14.770	1.207	62	69.607	.945
13	15.977	1.204	63	70.553	.938
14	17.181	1.201	64	71.490	.930
15	18.382	1.197	65	72.420	.924
16	19.579	1.194	66	73.344	.918
17	20.772	1.190	67	74.262	.910
18	21.963	1.186	68	75.172	.905
19	23.149	1.183	69	76.077	.899
20	24.332	1.180	70	76.976	.893
21	25.512	1.176	71	77.864	.887
22	26.688	1.172	72	78.746	.882
23	27.860	1.169	73	79.618	.876
24	29.029	1.164	74	80.480	.870
25	30.193	1.161	75	81.336	.864
26	31.354	1.156	76	82.182	.858
27	32.510	1.152	77	83.022	.853
28	33.662	1.147	78	83.855	.848
29	34.809	1.143	79	84.680	.843
30	35.952	1.139	80	85.499	.838
31	37.091	1.133	81	86.310	.833
32	38.224	1.128	82	87.110	.828
33	39.352	1.124	83	87.909	.823
34	40.476	1.118	84	88.677	.818
35	41.594	1.114	85	89.448	.813
36	42.708	1.108	86	90.212	.808
37	43.816	1.106	87	90.968	.803
38	44.919	1.097	88	91.716	.798
39	46.016	1.093	89	92.456	.793
40	47.109	1.086	90	93.188	.788
41	48.195	1.082	91	93.912	.783
42	49.277	1.076	92	94.637	.778
43	50.353	1.069	93	95.356	.773
44	51.422	1.064	94	96.017	.768
45	52.486	1.058	95	96.697	.763
46	53.544	1.051	96	97.370	.758
47	54.595	1.044	97	98.036	.753
48	55.639	1.039	98	98.696	.748
49	56.678	1.034	99	99.351	.743
50	57.712	-----	100	100.000	-----

TABLE 11.—Temperature corrections to readings of Saccharometers (standard at 20° C.)

[This table is calculated using the data on thermal expansion of sugar solutions by Plato,¹ assuming the instrument to be of Jena 16^{mm} glass. The table should be used with caution and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Temperature in degrees centigrade	Observed per cent of sugar													
	0	5	10	15	20	25	30	35	40	45	50	55	60	70
	Subtract from observed per cent													
0	0.30	0.49	0.65	0.77	0.89	0.99	1.08	1.16	1.24	1.31	1.37	1.41	1.44	1.49
5	.36	.47	.56	.65	.73	.80	.86	.91	.97	1.01	1.06	1.08	1.10	1.14
10	.32	.38	.43	.48	.52	.57	.60	.64	.67	.70	.72	.74	.75	.77
11	.31	.35	.40	.44	.48	.51	.55	.58	.60	.63	.65	.66	.68	.70
12	.29	.32	.36	.40	.43	.46	.50	.52	.54	.56	.58	.59	.60	.62
13	.26	.29	.32	.35	.38	.41	.44	.46	.48	.49	.51	.52	.53	.55
14	.24	.26	.29	.31	.34	.36	.38	.40	.41	.42	.44	.45	.46	.47
15	.20	.22	.24	.26	.28	.30	.32	.33	.34	.36	.36	.37	.38	.39
16	.17	.18	.20	.22	.23	.25	.26	.27	.28	.28	.29	.30	.31	.32
17	.13	.14	.15	.16	.18	.19	.20	.20	.21	.21	.22	.23	.23	.24
18	.09	.10	.10	.11	.12	.13	.13	.14	.14	.14	.15	.15	.15	.16
19	.05	.05	.05	.06	.06	.06	.07	.07	.07	.07	.08	.08	.08	.08
17.5	.11	.12	.12	.14	.15	.16	.16	.17	.17	.18	.18	.19	.19	.20
16.56 (60° F.)	.18	.20	.22	.24	.26	.28	.29	.30	.30	.32	.33	.33	.34	.34
	Add to observed per cent													
21	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09
22	.10	.10	.11	.12	.12	.13	.14	.14	.15	.15	.16	.16	.16	.16
23	.16	.16	.17	.17	.19	.20	.21	.21	.22	.23	.24	.24	.24	.24
24	.21	.22	.23	.24	.26	.27	.28	.29	.30	.31	.32	.32	.32	.32
25	.27	.28	.30	.31	.32	.34	.35	.36	.38	.38	.39	.39	.40	.39
26	.33	.34	.36	.37	.40	.40	.42	.44	.46	.47	.47	.48	.48	.48
27	.40	.41	.42	.44	.46	.48	.50	.52	.54	.54	.55	.56	.56	.56
28	.46	.47	.49	.51	.54	.56	.58	.60	.61	.62	.63	.64	.64	.64
29	.54	.55	.56	.59	.61	.63	.66	.68	.70	.70	.71	.72	.72	.72
30	.61	.62	.63	.66	.68	.71	.73	.76	.78	.78	.79	.80	.80	.81
35	.99	1.01	1.02	1.06	1.10	1.13	1.16	1.18	1.20	1.21	1.22	1.22	1.23	1.22
40	1.42	1.45	1.47	1.51	1.54	1.57	1.60	1.62	1.64	1.65	1.65	1.65	1.66	1.65
45	1.91	1.94	1.96	2.00	2.03	2.06	2.07	2.09	2.10	2.10	2.10	2.10	2.10	2.08
50	2.46	2.48	2.50	2.53	2.56	2.57	2.58	2.59	2.59	2.58	2.58	2.57	2.56	2.52
55	3.05	3.07	3.09	3.12	3.12	3.12	3.12	3.11	3.10	3.08	3.07	3.05	3.03	2.97
60	3.69	3.72	3.73	3.73	3.72	3.70	3.67	3.65	3.62	3.60	3.57	3.54	3.50	3.43
27.5	.43	.44	.46	.48	.50	.52	.54	.56	.58	.58	.59	.60	.60	.60

¹ Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 140; 1900.

TABLE 12.—Density¹ of solutions of cane sugar at 20° C.

[This table is the basis for standardizing hydrometers indicating per cent of sugar at 20° C.]

Per cent sugar	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051933	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055326	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095782	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106788	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114229	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166260	1.166775	1.167281	1.167786	1.168293	1.168800	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532

¹ According to Dr. F. Plato (Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 153; 1900).

TABLE 12.—Density of solutions of cane sugar at 20° C.—Continued

Per cent sugar	Tenths of per cent									
	0	1	2	3	4	5	6	7	8	9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246224	1.246796	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273033	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295911	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300079	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306068	1.306669	1.307271	1.307872	1.308475	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312698	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335342	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342796	1.343421	1.344046	1.344671	1.345296	1.345921	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353454	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363589	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378323
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.402452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408396	1.409061	1.409726	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422389	1.423059	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460496	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275
90	1.479976	1.480677	1.481378	1.482080	1.482782	1.483484	1.484187	1.484890	1.485593	1.486297
91	1.487002	1.487707	1.488411	1.489117	1.489823	1.490528	1.491234	1.491941	1.492647	1.493355
92	1.494063	1.494771	1.495479	1.496188	1.496897	1.497606	1.498316	1.499026	1.499736	1.500447
93	1.501158	1.501870	1.502582	1.503293	1.504006	1.504719	1.505432	1.506146	1.506859	1.507574
94	1.508289	1.509004	1.509720	1.510435	1.511151	1.511868	1.512585	1.513302	1.514019	1.514737
95	1.515455	1.516174	1.516893	1.517612	1.518332	1.519051	1.519771	1.520492	1.521212	1.521934
96	1.522656	1.523378	1.524100	1.524823	1.525546	1.526269	1.526993	1.527717	1.528441	1.529166
97	1.529891	1.530616	1.531342	1.532068	1.532794	1.533521	1.534248	1.534976	1.535704	1.536432
98	1.537161	1.537889	1.538618	1.539347	1.540076	1.540806	1.541536	1.542267	1.542998	1.543730
99	1.544462	1.545194	1.545926	1.546659	1.547392	1.548127	1.548861	1.549595	1.550329	1.551064
100	1.551800	-----	-----	-----	-----	-----	-----	-----	-----	-----

TABLE 13.—Density of solutions of sulphuric acid (H_2SO_4) at $20^\circ C$.[Calculated from Dr. J. Domke's table.¹ Adopted as the basis for standardization of hydrometers indicating per cent of sulphuric acid at $20^\circ C$.]

Per cent H_2SO_4	$D_{4}^{20}C$	Per cent H_2SO_4	$D_{4}^{20}C$	Per cent H_2SO_4	$D_{4}^{20}C$
0	0.99823	50	1.39505	91.0	1.81950
1	1.00506	51	1.40487	91.2	1.82045
2	1.01178	52	1.41481	91.4	1.82137
3	1.01839	53	1.42487	91.6	1.82227
4	1.02500	54	1.43503	91.8	1.82315
5	1.03168	55	1.44530	92.0	1.82401
6	1.03843	56	1.45568	92.2	1.82484
7	1.04527	57	1.46615	92.4	1.82564
8	1.05216	58	1.47673	92.6	1.82641
9	1.05909	59	1.48740	92.8	1.82717
10	1.06609	60	1.49818	93.0	1.82790
11	1.07314	61	1.50904	93.2	1.82860
12	1.08026	62	1.51999	93.4	1.82928
13	1.08744	63	1.53102	93.6	1.82993
14	1.09468	64	1.54213	93.8	1.83055
15	1.10199	65	1.55333	94.0	1.83115
16	1.10936	66	1.56460	94.2	1.83172
17	1.11679	67	1.57595	94.4	1.83226
18	1.12428	68	1.58739	94.6	1.83276
19	1.13183	69	1.59890	94.8	1.83324
20	1.13943	70	1.61048	95.0	1.83368
21	1.14709	71	1.62213	95.1	1.83389
22	1.15480	72	1.63384	95.2	1.83410
23	1.16258	73	1.64560	95.3	1.83430
24	1.17041	74	1.65738	95.4	1.83449
25	1.17830	75	1.66917	95.5	1.83469
26	1.18624	76	1.68095	95.6	1.83486
27	1.19423	77	1.69268	95.7	1.83503
28	1.20227	78	1.70433	95.8	1.83520
29	1.21036	79	1.71585	95.9	1.83534
30	1.21850	80	1.72717	96.0	1.83548
31	1.22669	81	1.73827	96.1	1.83560
32	1.23492	82	1.74904	96.2	1.83572
33	1.24320	83	1.75943	96.3	1.83584
34	1.25154	84	1.76932	96.4	1.83594
35	1.25992	85	1.77860	96.5	1.83604
36	1.26836	85.5	1.78300	96.6	1.83613
37	1.27685	86	1.78721	96.7	1.83621
38	1.28543	86.5	1.79124	96.8	1.83628
39	1.29407	87	1.79509	96.9	1.83634
40	1.30278	87.5	1.79875	97.0	1.83637
41	1.31157	88	1.80223	97.1	1.83639
42	1.32043	88.5	1.80552	97.2	1.83640
43	1.32938	89	1.80864	97.3	1.83640
44	1.33843	89.5	1.81159	97.4	1.83639
45	1.34759	90	1.81438	97.5	1.83637
46	1.35686	90.2	1.81545	97.6	1.83634
47	1.36625	90.4	1.81650	97.7	1.83629
48	1.37574	90.6	1.81753	97.8	1.83623
49	1.38533	90.8	1.81853	97.9	1.83615
50	1.39505	91.0	1.81950	98.0	1.83605

¹ Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 5, p. 131; 1900.

TABLE 14.—Temperature corrections to per cent of sulphuric acid determined by hydrometer (standard at 20° C.)

[Calculated from the same data as the preceding table, assuming Jena 16^{mm} glass as the material used. The table should be used with caution, and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air]

Observed Per cent H ₂ SO ₄	Temperature in degrees centigrade											
	0	5	10	15	25	30	35	40	45	50	55	60
	Subtract from observed per cent				Add to observed per cent							
0	-----	-----	-----	-----	0.16	0.35	0.59	0.86	1.17	1.5	1.9	2.1
5	0.59	0.49	0.36	0.20	.24	.50	.79	1.11	1.45	1.8	2.2	2.6
10	.92	.72	.51	.27	.29	.60	.93	1.28	1.65	2.0	2.4	2.8
20	1.39	1.06	.72	.36	.37	.75	1.14	1.53	1.93	2.3	2.7	3.1
30	1.64	1.23	.82	.41	.41	.82	1.24	1.65	2.07	2.5	2.9	3.3
40	1.65	1.24	.82	.41	.41	.82	1.22	1.62	2.03	2.4	2.8	3.2
50	1.56	1.17	.78	.39	.38	.77	1.15	1.52	1.90	2.3	2.6	3.0
60	1.52	1.14	.76	.38	.37	.74	1.11	1.48	1.84	2.2	2.6	2.9
70	1.54	1.15	.76	.38	.38	.75	1.13	1.50	1.86	2.2	2.6	3.0
80	1.72	1.30	.87	.44	.45	.90	1.36	1.83	2.31	2.8	3.3	3.8
81	1.76	1.34	.92	.44	.47	.93	1.42	1.93	2.44	3.0	3.5	4.0
82	1.84	1.41	.96	.47	.50	1.00	1.51	2.04	2.58	3.1	3.7	4.3
83	1.94	1.48	1.00	.50	.53	1.06	1.59	2.18	2.78	3.4	4.0	4.6
84	2.05	1.57	1.06	.53	.55	1.12	1.74	2.36	3.0	3.7	4.4	5.1
85	2.20	1.67	1.13	.57	.61	1.23	1.88	2.57	3.3	4.0	4.9	5.8
86	2.36	1.80	1.22	.62	.66	1.35	2.08	2.84	3.7	4.6	5.5	-----
87	2.54	1.95	1.32	.67	.73	1.50	2.31	3.2	4.1	5.2	-----	-----
88	2.75	2.12	1.44	.74	.81	1.67	2.59	3.6	4.7	6.0	-----	-----
89	3.01	2.31	1.58	.82	.89	1.86	2.91	4.1	5.6	-----	-----	-----
90	3.27	2.53	1.73	.91	.99	2.10	3.4	4.9	-----	-----	-----	-----
91	3.57	2.78	1.93	1.01	1.13	2.44	4.1	-----	-----	-----	-----	-----
92	3.91	3.06	2.13	1.12	1.32	3.00	-----	-----	-----	-----	-----	-----
93	4.29	3.38	2.37	1.26	1.64	-----	-----	-----	-----	-----	-----	-----
94	4.75	3.77	2.69	1.46	-----	-----	-----	-----	-----	-----	-----	-----
95	5.29	4.26	3.12	1.76	-----	-----	-----	-----	-----	-----	-----	-----
96	5.96	4.88	3.65	2.19	-----	-----	-----	-----	-----	-----	-----	-----
97	6.78	5.68	4.42	2.90	-----	-----	-----	-----	-----	-----	-----	-----

TABLE 15.—Temperature corrections to readings of specific gravity hydrometers in American petroleum oils at various temperatures

[Standard at 60°/60° F.]

Observed temperature °F.	Observed specific gravity						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
Subtract from observed specific gravity							
30	0.0188	0.0146	0.0135	0.0121	0.0111	0.0107	0.0107
32	.0148	.0126	.0126	.0113	.0104	.0100	.0100
34	.0137	.0126	.0116	.0106	.0097	.0098	.0093
36	.0126	.0116	.0107	.0097	.0089	.0085	.0086
38	.0115	.0106	.0098	.0089	.0082	.0078	.0078
40	.0105	.0097	.0089	.0081	.0074	.0071	.0071
42	.0094	.0087	.0080	.0072	.0066	.0064	.0064
44	.0083	.0077	.0071	.0064	.0059	.0057	.0057
46	.0072	.0067	.0062	.0056	.0052	.0050	.0050
48	.0062	.0057	.0052	.0048	.0045	.0043	.0043
50	.0052	.0048	.0044	.0040	.0037	.0036	.0035
52	.0042	.0038	.0035	.0032	.0030	.0028	.0028
54	.0031	.0029	.0025	.0024	.0022	.0021	.0021
56	.0020	.0019	.0017	.0016	.0015	.0014	.0014
58	.0010	.0010	.0009	.0008	.0007	.0007	.0007
Add to observed specific gravity							
60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	.0010	.0009	.0009	.0008	.0007	.0007	.0007
64	.0021	.0019	.0018	.0016	.0014	.0014	.0014
66	.0031	.0028	.0026	.0024	.0022	.0022	.0021
68	.0041	.0038	.0035	.0031	.0029	.0029	.0028
70	.0051	.0048	.0043	.0039	.0037	.0036	.0035
72	.0061	.0057	.0052	.0047	.0044	.0043	.0042
74	.0071	.0066	.0060	.0055	.0052	.0050	.0049
76	.0081	.0075	.0069	.0063	.0059	.0057	.0056
78	.0092	.0085	.0078	.0070	.0066	.0064	.0063
80	.0102	.0094	.0086	.0078	.0073	.0072	.0070
82	.0112	.0103	.0094	.0086	.0081	.0079	.0077
84	.0122	.0113	.0103	.0094	.0088	.0085	.0084
86	.0132	.0122	.0112	.0101	.0096	.0092	.0091
88	.0142	.0132	.0120	.0109	.0103	.0099	.0098
90	.0152	.0141	.0128	.0116	.0110	.0106	.0105
92	-----	.0151	.0136	.0123	.0117	.0114	.0112
94	-----	.0160	.0145	.0131	.0124	.0120	.0118
96	-----	.0169	.0153	.0137	.0130	.0127	.0125
98	-----	.0179	.0162	.0145	.0137	.0133	.0133
100	-----	.0188	.0170	.0153	.0144	.0141	.0139
102	-----	.0196	.0178	.0161	.0152	.0148	.0146
104	-----	.0205	.0186	.0168	.0159	.0155	.0153
106	-----	.0214	.0194	.0176	.0166	.0162	.0160
108	-----	.0223	.0202	.0184	.0173	.0169	.0166
110	-----	.0232	.0210	.0191	.0180	.0176	.0173
112	-----	.0240	.0218	.0198	.0187	.0183	.0180
114	-----	.0250	.0225	.0205	.0194	.0189	.0187
116	-----	.0258	.0233	.0213	.0201	.0196	.0194
118	-----	.0266	.0241	.0220	.0208	.0202	.0200
120	-----	.0275	.0249	.0227	.0215	.0210	.0207

(This table is calculated from the same data as Table 3, Circular No. 154, Bureau of Standards.)

For complete petroleum oil tables see Circular No. 154, Bureau of Standards.

TABLE 16.—Temperature corrections to readings of A. P. I. hydrometers in American petroleum oils at various temperatures

[Standard at 60° F.; modulus 141.5]

Observed temperature ° F.	Observed degrees A. P. I.							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	Add to observed degrees A. P. I.							
30	1.7	2.0	2.4	3.0	3.6	4.3	4.9	5.8
32	1.6	1.9	2.3	2.8	3.4	4.0	4.6	5.4
34	1.5	1.7	2.1	2.6	3.1	3.7	4.2	5.0
36	1.4	1.6	1.9	2.4	2.9	3.4	3.9	4.6
38	1.3	1.5	1.8	2.2	2.6	3.1	3.6	4.2
40	1.2	1.3	1.6	2.0	2.4	2.8	3.2	3.8
42	1.0	1.2	1.4	1.8	2.1	2.5	2.9	3.4
44	.9	1.0	1.3	1.6	1.9	2.2	2.6	3.0
46	.8	.9	1.1	1.4	1.6	1.9	2.2	2.6
48	.7	.8	1.0	1.2	1.4	1.7	1.9	2.2
50	.6	.7	.8	1.0	1.2	1.4	1.6	1.9
52	.5	.6	.6	.8	.9	1.1	1.3	1.5
54	.3	.4	.5	.6	.7	.8	1.0	1.1
56	.2	.2	.3	.4	.4	.5	.6	.7
58	.1	.1	.2	.2	.2	.3	.3	.3
Subtract from observed degrees A. P. I.								
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	.1	.1	.2	.2	.2	.2	.3	.3
64	.2	.3	.3	.4	.5	.5	.6	.7
66	.3	.4	.5	.6	.7	.8	.9	1.1
68	.5	.5	.6	.8	.9	1.1	1.2	1.4
70	.6	.7	.8	1.0	1.1	1.4	1.6	1.8
72	.7	.8	.9	1.1	1.4	1.6	1.9	2.2
74	.8	.9	1.1	1.3	1.6	1.9	2.2	2.5
76	.9	1.1	1.2	1.5	1.8	2.1	2.5	2.8
78	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.2
80	1.1	1.3	1.6	1.9	2.2	2.6	3.1	3.5
82	1.3	1.5	1.7	2.0	2.5	2.9	3.4	3.9
84	1.4	1.6	1.9	2.2	2.7	3.2	3.7	4.2
86	1.5	1.7	2.0	2.4	2.9	3.4	4.0	4.6
88	1.6	1.8	2.1	2.6	3.1	3.7	4.3	4.9
90	1.7	2.0	2.3	2.8	3.3	3.9	4.5	5.2
92	1.8	2.1	2.4	2.9	3.5	-----	-----	-----
94	1.9	2.2	2.6	3.1	3.8	-----	-----	-----
96	2.0	2.3	2.7	3.3	4.0	-----	-----	-----
98	2.1	2.5	2.9	3.4	4.2	-----	-----	-----
100	2.2	2.6	3.0	3.6	4.4	-----	-----	-----
102	2.4	2.7	3.2	3.8	4.6	-----	-----	-----
104	2.5	2.8	3.3	4.0	4.8	-----	-----	-----
106	2.6	3.0	3.5	4.1	5.0	-----	-----	-----
108	2.7	3.1	3.6	4.3	5.2	-----	-----	-----
110	2.8	3.2	3.8	4.5	5.4	-----	-----	-----
112	2.9	3.3	3.9	4.6	5.6	-----	-----	-----
114	3.0	3.5	4.0	4.8	5.8	-----	-----	-----
116	3.1	3.6	4.2	5.0	6.0	-----	-----	-----
118	3.2	3.7	4.3	5.1	6.2	-----	-----	-----
120	3.3	3.8	4.5	5.3	6.4	-----	-----	-----

(This table is calculated from the same data as Table 1, Circular No. 154, Bureau of Standards.)

For complete petroleum oil tables see Circular No. 154, Bureau of Standards.

NOTE.—In order to overcome the confusion that has existed in the petroleum-oil industry by reason of the use of two so-called Baumé scales for light liquids, the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards in December, 1921, agreed to recommend that in the future only the scale based on the modulus 141.5 be used in the petroleum-oil industry, and that it be known as the A. P. I. scale. The relation of degrees A. P. I. to specific gravity is expressed by the formula

$$\text{Degrees A. P. I.} = \frac{141.5}{\text{Sp. Gr. } 60^{\circ}/60^{\circ} \text{ F.}} - 131.5$$

The U. S. Baumé scale based on the modulus 140 will continue to be used for other liquids lighter than water.

(See Tables 24 and 25 of this circular for the relation of degrees A. P. I. to specific gravity.)

TABLE 17.—Degrees Baumé, degrees A. P. I.,¹ pounds per gallon, and gallons per pound corresponding to various specific gravities

Specific gravity 60°/60° F.	Degrees Baumé (modulus 140)	Degrees A. P. I. (modulus 141.5)	Pounds per gallon	Gallons per pound
0.600	103.33	104.33	4.993	0.2003
.610	99.51	100.47	5.076	.1970
.620	95.81	96.73	5.160	.1938
.630	92.22	93.10	5.243	.1907
.640	88.75	89.59	5.326	.1877
.650	85.38	86.19	5.410	.1848
.660	82.12	82.89	5.493	.1820
.670	78.96	79.69	5.577	.1793
.680	75.88	76.59	5.660	.1767
.690	72.90	73.57	5.743	.1741
.700	70.00	70.64	5.827	.1716
.710	67.18	67.80	5.910	.1692
.720	64.44	65.03	5.994	.1668
.730	61.78	62.34	6.077	.1646
.740	59.19	59.72	6.160	.1623
.750	56.67	57.17	6.244	.1602
.760	54.21	54.68	6.327	.1580
.770	51.82	52.27	6.410	.1560
.780	49.49	49.91	6.494	.1540
.790	47.22	47.61	6.577	.1520
.800	45.00	45.38	6.661	.1501
.810	42.84	43.19	6.744	.1483
.820	40.73	41.06	6.827	.1465
.830	38.68	38.98	6.911	.1447
.840	36.67	36.95	6.994	.1430
.850	34.71	34.97	7.078	.1413
.860	32.79	33.03	7.161	.1396
.870	30.92	31.14	7.244	.1380
.880	29.09	29.30	7.328	.1365
.890	27.30	27.49	7.411	.1349
.900	25.56	25.72	7.494	.1334
.910	23.85	23.99	7.578	.1320
.920	22.17	22.30	7.661	.1306
.930	20.54	20.65	7.745	.1291
.940	18.94	19.03	7.828	.1278
.950	17.37	17.45	7.911	.1264
.960	15.83	15.90	7.995	.1251
.970	14.33	14.38	8.078	.1238
.980	12.86	12.89	8.162	.1226
.990	11.41	11.43	8.245	.1213
1.000	10.00	10.00	8.328	.1201

¹ See note, p. 29.

For complete petroleum oil tables see Circular No. 154, Bureau of Standards.

TABLE 18.—Specific gravities, pounds per gallon, and gallons per pound corresponding to various degrees Baumé for light liquids

Degrees Baumé (modulus 140)	Specific gravity 60°/60° F.	Pounds per gallon	Gallons per pound	Degrees Baumé (modulus 140)	Specific gravity 60°/60° F.	Pounds per gallon	Gallons per Pound
10.0	1.0000	8.328	0.1201	55.0	0.7568	6.300	0.1587
11.0	.9929	8.269	.1209	56.0	.7527	6.266	.1596
12.0	.9859	8.211	.1218	57.0	.7487	6.233	.1604
13.0	.9790	8.153	.1227	58.0	.7447	6.199	.1613
14.0	.9722	8.096	.1235	59.0	.7407	6.166	.1622
15.0	.9655	8.041	.1244	60.0	.7368	6.134	.1630
16.0	.9589	7.986	.1252	61.0	.7330	6.102	.1639
17.0	.9524	7.931	.1261	62.0	.7292	6.070	.1647
18.0	.9459	7.877	.1270	63.0	.7254	6.038	.1656
19.0	.9396	7.825	.1278	64.0	.7216	6.007	.1665
20.0	.9333	7.772	.1287	65.0	.7179	5.976	.1673
21.0	.9272	7.721	.1295	66.0	.7143	5.946	.1682
22.0	.9211	7.670	.1304	67.0	.7107	5.916	.1690
23.0	.9150	7.620	.1313	68.0	.7071	5.886	.1699
24.0	.9091	7.570	.1321	69.0	.7035	5.856	.1708
25.0	.9032	7.522	.1330	70.0	.7000	5.827	.1716
26.0	.8974	7.473	.1338	71.0	.6965	5.798	.1725
27.0	.8917	7.425	.1347	72.0	.6931	5.769	.1733
28.0	.8861	7.378	.1355	73.0	.6897	5.741	.1742
29.0	.8805	7.332	.1364	74.0	.6863	5.712	.1751
30.0	.8750	7.286	.1373	75.0	.6829	5.685	.1759
31.0	.8696	7.241	.1381	76.0	.6796	5.657	.1768
32.0	.8642	7.196	.1390	77.0	.6763	5.629	.1776
33.0	.8589	7.152	.1398	78.0	.6731	5.602	.1785
34.0	.8537	7.108	.1407	79.0	.6699	5.576	.1793
35.0	.8485	7.065	.1415	80.0	.6667	5.549	.1802
36.0	.8434	7.022	.1424	81.0	.6635	5.522	.1811
37.0	.8383	6.980	.1433	82.0	.6604	5.497	.1819
38.0	.8333	6.939	.1441	83.0	.6573	5.471	.1828
39.0	.8284	6.898	.1450	84.0	.6542	5.445	.1837
40.0	.8235	6.857	.1459	85.0	.6512	5.420	.1845
41.0	.8187	6.817	.1467	86.0	.6482	5.395	.1854
42.0	.8140	6.777	.1476	87.0	.6452	5.370	.1862
43.0	.8092	6.738	.1484	88.0	.6422	5.345	.1871
44.0	.8046	6.699	.1493	89.0	.6393	5.320	.1880
45.0	.8000	6.661	.1501	90.0	.6364	5.296	.1888
46.0	.7955	6.623	.1510	91.0	.6335	5.272	.1897
47.0	.7910	6.586	.1518	92.0	.6306	5.248	.1905
48.0	.7865	6.548	.1527	93.0	.6278	5.225	.1914
49.0	.7821	6.511	.1536	94.0	.6250	5.201	.1923
50.0	.7778	6.476	.1544	95.0	.6222	5.178	.1931
51.0	.7735	6.440	.1553	96.0	.6195	5.155	.1940
52.0	.7692	6.404	.1562	97.0	.6167	5.132	.1949
53.0	.7650	6.369	.1570	98.0	.6140	5.110	.1957
54.0	.7609	6.334	.1579	99.0	.6114	5.088	.1966
55.0	.7568	6.300	.1587	100.0	.6087	5.066	.1974

105396°—24†—3

TABLE 19.—Specific gravities, pounds per gallon, and gallons per pound corresponding to various degrees A. P. I.¹

Degrees A. P. I. (modulus 141.5)	Specific gravity 60°/60° F.	Pounds per gallon	Gallons per pound	Degrees A. P. I. (modulus 141.5)	Specific gravity 60°/60° F.	Pounds per gallon	Gallons per pound
10.0	1.0000	8.328	0.1201	55.0	0.7587	6.316	0.1583
11.0	.9930	8.270	.1209	56.0	.7547	6.283	.1592
12.0	.9861	8.212	.1218	57.0	.7507	6.249	.1600
13.0	.9792	8.155	.1226	58.0	.7467	6.216	.1609
14.0	.9725	8.099	.1235	59.0	.7428	6.184	.1617
15.0	.9659	8.044	.1243	60.0	.7389	6.151	.1626
16.0	.9593	7.989	.1252	61.0	.7351	6.119	.1634
17.0	.9529	7.935	.1260	62.0	.7313	6.087	.1643
18.0	.9465	7.882	.1269	63.0	.7275	6.056	.1651
19.0	.9402	7.830	.1277	64.0	.7238	6.025	.1660
20.0	.9340	7.778	.1286	65.0	.7201	5.994	.1668
21.0	.9279	7.727	.1294	66.0	.7165	5.964	.1677
22.0	.9218	7.676	.1303	67.0	.7128	5.934	.1685
23.0	.9159	7.627	.1311	68.0	.7093	5.904	.1694
24.0	.9100	7.578	.1320	69.0	.7057	5.874	.1702
25.0	.9042	7.529	.1328	70.0	.7022	5.845	.1711
26.0	.8984	7.481	.1337	71.0	.6988	5.817	.1719
27.0	.8927	7.434	.1345	72.0	.6953	5.788	.1728
28.0	.8871	7.387	.1354	73.0	.6919	5.759	.1736
29.0	.8816	7.341	.1362	74.0	.6886	5.731	.1745
30.0	.8762	7.296	.1371	75.0	.6852	5.703	.1753
31.0	.8708	7.251	.1379	76.0	.6819	5.676	.1762
32.0	.8654	7.206	.1388	77.0	.6787	5.649	.1770
33.0	.8602	7.163	.1396	78.0	.6754	5.622	.1779
34.0	.8550	7.119	.1405	79.0	.6722	5.595	.1787
35.0	.8498	7.076	.1413	80.0	.6690	5.568	.1796
36.0	.8448	7.034	.1422	81.0	.6659	5.542	.1804
37.0	.8398	6.993	.1430	82.0	.6628	5.516	.1813
38.0	.8348	6.951	.1439	83.0	.6597	5.491	.1821
39.0	.8299	6.910	.1447	84.0	.6566	5.465	.1830
40.0	.8251	6.870	.1456	85.0	.6536	5.440	.1838
41.0	.8203	6.830	.1464	86.0	.6506	5.415	.1847
42.0	.8155	6.790	.1473	87.0	.6476	5.390	.1855
43.0	.8109	6.752	.1481	88.0	.6446	5.365	.1864
44.0	.8063	6.713	.1490	89.0	.6417	5.341	.1872
45.0	.8017	6.675	.1498	90.0	.6388	5.316	.1881
46.0	.7972	6.637	.1507	91.0	.6360	5.293	.1889
47.0	.7927	6.600	.1515	92.0	.6331	5.269	.1898
48.0	.7883	6.563	.1524	93.0	.6303	5.246	.1906
49.0	.7839	6.526	.1532	94.0	.6275	5.222	.1915
50.0	.7796	6.490	.1541	95.0	.6247	5.199	.1923
51.0	.7753	6.455	.1549	96.0	.6220	5.176	.1932
52.0	.7711	6.420	.1558	97.0	.6193	5.154	.1940
53.0	.7669	6.385	.1566	98.0	.6166	5.131	.1949
54.0	.7628	6.350	.1575	99.0	.6139	5.109	.1957
55.0	.7587	6.316	.1583	100.0	.6112	5.086	.1966

¹ See note, p. 29.

For complete petroleum oil tables see circular No. 154, Bureau of Standards.

**TABLE 20.—Degrees Baumé corresponding to specific gravities at $\frac{60^\circ}{60^\circ}$ F. ($\frac{15^\circ 56}{15^\circ 56}$ C.)
for liquids heavier than water**

[Calculated from the formula $\text{degrees Baumé} = 145 - \frac{145}{D_{\frac{60^\circ}{60^\circ} \text{ F.}}}$ which defines the Baumé scale, in general use in the United States, for liquids heavier than water]

D $\frac{15^\circ 56}{15^\circ 56}$ C.	0	1	2	3	4	5	6	7	8	9	Diff.
1.00	0.000	0.145	0.289	0.434	0.578	0.721	0.865	1.008	1.151	1.293	143
1.01	1.436	1.578	1.719	1.861	2.002	2.143	2.283	2.424	2.564	2.704	141
1.02	2.843	2.982	3.121	3.260	3.399	3.537	3.675	3.812	3.950	4.087	138
1.03	4.223	4.360	4.496	4.632	4.768	4.903	5.038	5.174	5.308	5.443	136
1.04	5.577	5.711	5.845	5.978	6.111	6.244	6.377	6.509	6.641	6.773	133
1.05	6.905	7.036	7.167	7.298	7.429	7.559	7.689	7.819	7.949	8.078	130
1.06	8.208	8.336	8.465	8.594	8.722	8.850	8.978	9.106	9.232	9.359	128
1.07	9.486	9.613	9.739	9.865	9.991	10.116	10.242	10.367	10.492	10.616	126
1.08	10.741	10.865	10.989	11.113	11.236	11.359	11.483	11.605	11.728	11.850	124
1.09	11.972	12.094	12.216	12.338	12.459	12.580	12.701	12.821	12.942	13.062	121
1.10	13.182	13.302	13.421	13.540	13.659	13.778	13.897	14.015	14.134	14.252	119
1.11	14.370	14.487	14.604	14.721	14.838	14.955	15.072	15.188	15.304	15.420	117
1.12	15.536	15.651	15.767	15.882	15.997	16.111	16.226	16.340	16.454	16.568	115
1.13	16.682	16.795	16.908	17.021	17.134	17.247	17.359	17.471	17.583	17.695	113
1.14	17.807	17.919	18.030	18.141	18.252	18.363	18.473	18.583	18.693	18.803	111
1.15	18.913	19.023	19.132	19.241	19.350	19.459	19.568	19.676	19.784	19.892	109
1.16	20.000	20.108	20.215	20.322	20.430	20.536	20.643	20.750	20.856	20.962	107
1.17	21.068	21.174	21.280	21.385	21.491	21.596	21.701	21.806	21.910	22.014	106
1.18	22.119	22.223	22.327	22.430	22.534	22.637	22.740	22.843	22.946	23.049	103
1.19	23.151	23.254	23.356	23.458	23.560	23.661	23.763	23.864	23.965	24.066	101
1.20	24.167	24.267	24.368	24.468	24.568	24.668	24.768	24.868	24.967	25.066	100
1.21	25.165	25.264	25.363	25.462	25.560	25.658	25.755	25.855	25.952	26.050	98
1.22	26.148	26.245	26.342	26.439	26.536	26.633	26.729	26.826	26.922	27.018	97
1.23	27.114	27.210	27.305	27.401	27.496	27.591	27.686	27.781	27.876	27.970	95
1.24	28.065	28.159	28.253	28.347	28.441	28.534	28.628	28.721	28.814	28.907	94
1.25	29.000	29.093	29.185	29.278	29.370	29.462	29.554	29.646	29.738	29.829	92
1.26	29.921	30.012	30.103	30.194	30.285	30.376	30.466	30.556	30.647	30.737	91
1.27	30.827	30.917	31.006	31.096	31.185	31.275	31.364	31.453	31.542	31.630	89
1.28	31.719	31.807	31.896	31.984	32.072	32.160	32.247	32.335	32.422	32.510	88
1.29	32.597	32.684	32.771	32.858	32.944	33.031	33.117	33.204	33.290	33.376	87
1.30	33.462	33.547	33.633	33.718	33.804	33.889	33.974	34.059	34.144	34.229	86
1.31	34.313	34.397	34.482	34.566	34.650	34.734	34.818	34.901	34.985	35.068	84
1.32	35.152	35.235	35.318	35.401	35.483	35.566	35.649	35.731	35.813	35.895	83
1.33	35.977	36.059	36.141	36.223	36.304	36.386	36.467	36.548	36.629	36.710	81
1.34	36.791	36.872	36.952	37.033	37.113	37.193	37.273	37.353	37.433	37.513	80
1.35	37.593	37.672	37.751	37.831	37.910	37.989	38.068	38.147	38.225	38.304	79
1.36	38.382	38.461	38.539	38.617	38.695	38.773	38.851	38.928	39.006	39.083	78
1.37	39.161	39.238	39.315	39.392	39.469	39.546	39.622	39.699	39.775	39.851	77
1.38	39.928	40.004	40.080	40.156	40.231	40.307	40.382	40.458	40.533	40.608	76
1.39	40.683	40.758	40.833	40.908	40.983	41.057	41.132	41.206	41.280	41.355	75
1.40	41.429	41.503	41.576	41.650	41.724	41.797	41.871	41.944	42.017	42.090	74
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73

TABLE 20.—Degrees Baumé corresponding to specific gravities at $60^{\circ} F. \left(\frac{15^{\circ}56}{15^{\circ}56} C. \right)$
for liquids heavier than water—Continued

D $\frac{15^{\circ}56}{15^{\circ}56} C.$	0	1	2	3	4	5	6	7	8	9	Diff.
1.41	42.163	42.236	42.309	42.381	42.454	42.527	42.599	42.671	42.743	42.815	73
1.42	42.887	42.959	43.031	43.103	43.174	43.246	43.317	43.388	43.459	43.530	72
1.43	43.601	43.672	43.743	43.814	43.884	43.955	44.025	44.095	44.166	44.236	71
1.44	44.306	44.376	44.445	44.515	44.585	44.654	44.724	44.793	44.862	44.931	70
1.45	45.000	45.069	45.138	45.207	45.275	45.344	45.412	45.481	45.549	45.617	69
1.46	45.685	45.753	45.821	45.889	45.956	46.024	46.091	46.159	46.226	46.293	67
1.47	46.361	46.428	46.495	46.562	46.628	46.695	46.762	46.828	46.894	46.961	67
1.48	47.027	47.093	47.159	47.225	47.291	47.357	47.423	47.488	47.554	47.619	66
1.49	47.685	47.750	47.815	47.880	47.945	48.010	48.075	48.140	48.204	48.269	65
1.50	48.333	48.398	48.462	48.526	48.591	48.655	48.719	48.782	48.846	48.910	64
1.51	48.974	49.037	49.101	49.164	49.227	49.290	49.354	49.417	49.480	49.543	63
1.52	49.605	49.668	49.731	49.793	49.856	49.918	49.980	50.043	50.105	50.167	62
1.53	50.229	50.291	50.353	50.414	50.476	50.538	50.599	50.660	50.722	50.783	61
1.54	50.844	50.905	50.966	51.027	51.088	51.149	51.210	51.271	51.331	51.391	61
1.55	51.452	51.512	51.572	51.632	51.692	51.752	51.812	51.872	51.932	51.992	60
1.56	52.051	52.111	52.170	52.230	52.289	52.348	52.407	52.467	52.526	52.585	59
1.57	52.643	52.702	52.761	52.820	52.878	52.937	52.995	53.053	53.112	53.170	59
1.58	53.228	53.286	53.344	53.402	53.460	53.517	53.575	53.633	53.690	53.748	58
1.59	53.805	53.862	53.920	53.977	54.034	54.091	54.148	54.205	54.262	54.318	57
1.60	54.375	54.432	54.488	54.545	54.601	54.657	54.714	54.770	54.826	54.882	56
1.61	54.938	54.994	55.050	55.106	55.161	55.217	55.272	55.328	55.383	55.439	56
1.62	55.494	55.549	55.604	55.659	55.714	55.769	55.824	55.879	55.934	55.988	55
1.63	56.043	56.098	56.152	56.206	56.261	56.315	56.369	56.423	56.478	56.531	54
1.64	56.585	56.639	56.693	56.747	56.801	56.854	56.908	56.961	57.015	57.068	54
1.65	57.121	57.175	57.228	57.281	57.334	57.387	57.440	57.493	57.546	57.598	53
1.66	57.651	57.703	57.756	57.808	57.861	57.913	57.965	58.017	58.070	58.122	52
1.67	58.174	58.226	58.278	58.329	58.381	58.433	58.485	58.536	58.588	58.639	52
1.68	58.690	58.742	58.793	58.844	58.896	58.947	58.998	59.049	59.100	59.150	51
1.69	59.201	59.252	59.303	59.353	59.404	59.454	59.505	59.555	59.605	59.656	50
1.70	59.706	59.756	59.806	59.856	59.906	59.956	60.006	60.056	60.105	60.155	50
1.71	60.205	60.254	60.304	60.353	60.403	60.452	60.501	60.550	60.600	60.649	49
1.72	60.698	60.747	60.796	60.844	60.893	60.942	60.991	61.039	61.088	61.136	49
1.73	61.185	61.234	61.282	61.330	61.378	61.427	61.475	61.523	61.571	61.619	48
1.74	61.667	61.715	61.762	61.810	61.858	61.906	61.953	62.001	62.048	62.096	48
1.75	62.143	62.190	62.237	62.285	62.332	62.379	62.426	62.473	62.520	62.567	47
1.76	62.614	62.660	62.707	62.754	62.801	62.847	62.894	62.940	62.987	63.033	46
1.77	63.079	63.125	63.172	63.218	63.264	63.310	63.356	63.402	63.448	63.494	46
1.78	63.539	63.585	63.631	63.676	63.722	63.768	63.813	63.858	63.904	63.949	46
1.79	63.994	64.040	64.085	64.130	64.175	64.220	64.265	64.310	64.355	64.400	45
1.80	64.445	64.489	64.534	64.579	64.623	64.668	64.712	64.757	64.801	64.845	45
1.81	64.890	64.934	64.978	65.022	65.066	65.110	65.154	65.198	65.242	65.286	44
1.82	65.330	65.374	65.417	65.461	65.504	65.548	65.591	65.635	65.678	65.722	43
1.83	65.765	65.808	65.852	65.895	65.938	65.981	66.024	66.067	66.110	66.153	43
1.84	66.196	66.238	66.281	66.324	66.367	66.409	66.452	66.494	66.537	66.579	42
1.85	66.622										

TABLE 21.—Specific gravities at 60° F. $\left(\frac{15.56}{15.56} C.\right)$ Corresponding to degrees Baumé for liquids heavier than water

[Calculated from the formula specific gravity 60° F. = $\frac{145}{145 - \text{Deg. Baumé}}$]

Degrees Baumé	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	1.0007	1.0014	1.0021	1.0028	1.0035	1.0042	1.0049	1.0055	1.0062
1	1.0069	1.0076	1.0083	1.0090	1.0097	1.0105	1.0112	1.0119	1.0126	1.0133
2	1.0140	1.0147	1.0154	1.0161	1.0168	1.0175	1.0183	1.0190	1.0197	1.0204
3	1.0211	1.0218	1.0226	1.0233	1.0240	1.0247	1.0255	1.0262	1.0269	1.0276
4	1.0284	1.0291	1.0298	1.0306	1.0313	1.0320	1.0328	1.0335	1.0342	1.0350
5	1.0357	1.0365	1.0372	1.0379	1.0387	1.0394	1.0402	1.0409	1.0417	1.0424
6	1.0432	1.0439	1.0447	1.0454	1.0462	1.0469	1.0477	1.0484	1.0492	1.0500
7	1.0507	1.0515	1.0522	1.0530	1.0538	1.0545	1.0553	1.0561	1.0569	1.0576
8	1.0584	1.0592	1.0599	1.0607	1.0615	1.0623	1.0630	1.0638	1.0646	1.0654
9	1.0662	1.0670	1.0677	1.0685	1.0693	1.0701	1.0709	1.0717	1.0725	1.0733
10	1.0741	1.0749	1.0757	1.0765	1.0773	1.0781	1.0789	1.0797	1.0805	1.0813
11	1.0821	1.0829	1.0837	1.0845	1.0853	1.0861	1.0870	1.0878	1.0886	1.0894
12	1.0902	1.0910	1.0919	1.0927	1.0935	1.0943	1.0952	1.0960	1.0968	1.0977
13	1.0985	1.0993	1.1002	1.1010	1.1019	1.1027	1.1035	1.1043	1.1052	1.1060
14	1.1069	1.1077	1.1086	1.1094	1.1103	1.1111	1.1120	1.1128	1.1137	1.1145
15	1.1154	1.1162	1.1171	1.1180	1.1188	1.1197	1.1206	1.1214	1.1223	1.1232
16	1.1240	1.1249	1.1258	1.1267	1.1275	1.1284	1.1293	1.1302	1.1310	1.1319
17	1.1328	1.1337	1.1346	1.1355	1.1364	1.1373	1.1381	1.1390	1.1399	1.1408
18	1.1417	1.1426	1.1435	1.1444	1.1453	1.1462	1.1472	1.1481	1.1490	1.1499
19	1.1508	1.1517	1.1526	1.1535	1.1545	1.1554	1.1563	1.1572	1.1581	1.1591
20	1.1600	1.1609	1.1619	1.1628	1.1637	1.1647	1.1656	1.1665	1.1675	1.1684
21	1.1694	1.1703	1.1712	1.1722	1.1731	1.1741	1.1750	1.1760	1.1769	1.1779
22	1.1789	1.1798	1.1808	1.1817	1.1827	1.1837	1.1846	1.1856	1.1866	1.1876
23	1.1885	1.1895	1.1905	1.1915	1.1924	1.1934	1.1944	1.1954	1.1964	1.1974
24	1.1983	1.1993	1.2003	1.2013	1.2023	1.2033	1.2043	1.2053	1.2063	1.2073
25	1.2083	1.2093	1.2104	1.2114	1.2124	1.2134	1.2144	1.2154	1.2164	1.2175
26	1.2186	1.2196	1.2206	1.2216	1.2226	1.2236	1.2247	1.2257	1.2267	1.2278
27	1.2288	1.2299	1.2309	1.2319	1.2330	1.2340	1.2351	1.2361	1.2372	1.2383
28	1.2393	1.2404	1.2414	1.2425	1.2436	1.2446	1.2457	1.2468	1.2478	1.2489
29	1.2500	1.2511	1.2522	1.2532	1.2543	1.2554	1.2565	1.2576	1.2587	1.2598
30	1.2609	1.2620	1.2631	1.2642	1.2653	1.2664	1.2675	1.2686	1.2697	1.2708
31	1.2719	1.2730	1.2742	1.2753	1.2764	1.2775	1.2787	1.2798	1.2809	1.2821
32	1.2832	1.2843	1.2855	1.2866	1.2877	1.2889	1.2900	1.2912	1.2923	1.2935
33	1.2946	1.2958	1.2970	1.2981	1.2993	1.3004	1.3016	1.3028	1.3040	1.3051
34	1.3063	1.3075	1.3087	1.3098	1.3110	1.3122	1.3134	1.3146	1.3158	1.3170
35	1.3182	1.3194	1.3206	1.3218	1.3230	1.3242	1.3254	1.3266	1.3278	1.3291
36	1.3303	1.3315	1.3327	1.3339	1.3352	1.3364	1.3376	1.3389	1.3401	1.3414
37	1.3426	1.3438	1.3451	1.3463	1.3476	1.3488	1.3501	1.3514	1.3526	1.3539
38	1.3551	1.3564	1.3577	1.3590	1.3602	1.3615	1.3628	1.3641	1.3653	1.3666
39	1.3679	1.3692	1.3705	1.3718	1.3731	1.3744	1.3757	1.3770	1.3783	1.3796
40	1.3810	1.3823	1.3836	1.3849	1.3862	1.3876	1.3889	1.3902	1.3916	1.3929
41	1.3942	1.3956	1.3969	1.3983	1.3996	1.4010	1.4023	1.4037	1.4050	1.4064
42	1.4078	1.4091	1.4105	1.4119	1.4133	1.4146	1.4160	1.4174	1.4188	1.4202
43	1.4216	1.4230	1.4244	1.4258	1.4272	1.4286	1.4300	1.4314	1.4328	1.4342
44	1.4356	1.4371	1.4385	1.4399	1.4414	1.4428	1.4442	1.4457	1.4471	1.4486
45	1.4500	1.4515	1.4529	1.4544	1.4558	1.4573	1.4588	1.4602	1.4617	1.4632
46	1.4646	1.4661	1.4676	1.4691	1.4706	1.4721	1.4736	1.4751	1.4766	1.4781
47	1.4796	1.4811	1.4826	1.4841	1.4857	1.4872	1.4887	1.4902	1.4918	1.4933
48	1.4948	1.4964	1.4979	1.4995	1.5010	1.5026	1.5041	1.5057	1.5073	1.5088
49	1.5104	1.5120	1.5136	1.5152	1.5167	1.5183	1.5199	1.5215	1.5231	1.5247
50	1.5263	1.5279	1.5295	1.5312	1.5328	1.5344	1.5360	1.5376	1.5393	1.5409
51	1.5426	1.5442	1.5458	1.5475	1.5491	1.5508	1.5525	1.5541	1.5558	1.5575
52	1.5591	1.5608	1.5625	1.5642	1.5659	1.5676	1.5693	1.5710	1.5727	1.5744
53	1.5761	1.5778	1.5795	1.5812	1.5830	1.5847	1.5864	1.5882	1.5899	1.5917
54	1.5934	1.5952	1.5969	1.5987	1.6004	1.6022	1.6040	1.6058	1.6075	1.6093
55	1.6111	1.6129	1.6147	1.6165	1.6183	1.6201	1.6219	1.6237	1.6256	1.6274
56	1.6292	1.6310	1.6329	1.6347	1.6366	1.6384	1.6403	1.6421	1.6440	1.6459
57	1.6477	1.6496	1.6515	1.6534	1.6553	1.6571	1.6590	1.6609	1.6628	1.6648
58	1.6667	1.6686	1.6705	1.6724	1.6744	1.6763	1.6782	1.6802	1.6821	1.6841
59	1.6860	1.6880	1.6900	1.6919	1.6939	1.6959	1.6979	1.6999	1.7019	1.7039
60	1.7059	1.7079	1.7099	1.7119	1.7139	1.7160	1.7180	1.7200	1.7221	1.7241
61	1.7262	1.7282	1.7303	1.7324	1.7344	1.7365	1.7386	1.7407	1.7428	1.7449
62	1.7470	1.7491	1.7512	1.7533	1.7554	1.7576	1.7597	1.7618	1.7640	1.7661
63	1.7683	1.7705	1.7726	1.7748	1.7770	1.7791	1.7813	1.7835	1.7857	1.7879
64	1.7901	1.7923	1.7946	1.7968	1.7990	1.8012	1.8035	1.8057	1.8080	1.8102
65	1.8125	1.8148	1.8170	1.8193	1.8216	1.8239	1.8262	1.8285	1.8308	1.8331
66	1.8354	1.8378	1.8401	1.8424	1.8448	1.8471	1.8495	1.8519	1.8542	1.8566
67	1.8590	1.8614	1.8638	1.8662	1.8686	1.8710	1.8734	1.8758	1.8782	1.8807
68	1.8831	1.8856	1.8880	1.8905	1.8930	1.8954	1.8979	1.9004	1.9029	1.9054
69	1.9079	1.9104	1.9129	1.9155	1.9180	1.9205	1.9231	1.9256	1.9282	1.9308
70	1.9333									

TABLE 22.—Degrees Baumé corresponding to specific gravities at 60° F. $\left(\frac{15^{\circ}56}{15^{\circ}56} C.\right)$
for liquids lighter than water

[Calculated from the formula degrees Baumé = $\frac{140}{D_{60^{\circ}F.}} - 130$ which defines the Baumé scale, in general use

in the United States, for liquids lighter than water]

$\frac{15^{\circ}56}{15^{\circ}56} C.$	0	1	2	3	4	5	6	7	8	9	Diff.
0.60	103.333	102.945	102.558	102.172	101.788	101.405	101.023	100.642	100.263	99.885	382
.61	99.508	99.133	98.758	98.385	98.013	97.642	97.273	96.904	96.537	96.171	370
.62	95.806	95.443	95.080	94.719	94.359	94.000	93.642	93.285	92.930	92.576	360
.63	92.222	91.870	91.519	91.169	90.820	90.472	90.126	89.780	89.436	89.092	348
.64	88.750	88.409	88.068	87.729	87.391	87.054	86.718	86.383	86.049	85.716	337
.65	85.385	85.054	84.724	84.395	84.067	83.741	83.415	83.090	82.766	82.443	327
.66	82.121	81.800	81.480	81.161	80.843	80.526	80.210	79.895	79.581	79.268	317
.67	78.955	78.644	78.333	78.024	77.715	77.407	77.101	76.795	76.490	76.186	308
.68	75.882	75.580	75.279	74.978	74.678	74.380	74.082	73.785	73.488	73.193	298
.69	72.899	72.605	72.312	72.020	71.729	71.439	71.149	70.861	70.573	70.286	290
.70	70.000	69.715	69.430	69.146	68.864	68.582	68.300	68.020	67.740	67.461	282
.71	67.183	66.906	66.629	66.354	66.078	65.804	65.531	65.258	64.986	64.715	274
.72	64.444	64.175	63.906	63.638	63.370	63.103	62.837	62.572	62.308	62.044	266
.73	61.781	61.518	61.257	60.996	60.736	60.476	60.217	59.959	59.702	59.445	260
.74	59.189	58.934	58.679	58.425	58.172	57.919	57.668	57.416	57.166	56.916	252
.75	56.667	56.418	56.170	55.923	55.676	55.430	55.185	54.941	54.697	54.453	246
.76	54.210	53.968	53.727	53.486	53.246	53.007	52.768	52.529	52.292	52.055	239
.77	51.818	51.582	51.347	51.113	50.879	50.645	50.412	50.180	49.949	49.718	234
.78	49.487	49.257	49.028	48.799	48.571	48.344	48.117	47.891	47.665	47.440	227
.79	47.215	46.991	46.768	46.545	46.322	46.101	45.879	45.659	45.439	45.219	222
.80	45.000	44.781	44.564	44.346	44.129	43.913	43.697	43.482	43.267	43.053	216
.81	42.840	42.626	42.414	42.202	41.990	41.779	41.569	41.359	41.149	40.940	210
.82	40.732	40.524	40.316	40.109	39.903	39.697	39.492	39.287	39.082	38.878	206
.83	38.675	38.472	38.269	38.067	37.866	37.665	37.464	37.264	37.064	36.866	201
.84	36.667	36.469	36.271	36.074	35.877	35.680	35.485	35.289	35.094	34.900	196
.85	34.706	34.512	34.319	34.127	33.934	33.743	33.551	33.361	33.170	32.980	192
.86	32.791	32.602	32.413	32.225	32.037	31.850	31.663	31.476	31.290	31.105	187
.87	30.920	30.735	30.550	30.366	30.183	30.000	29.817	29.635	29.453	29.272	183
.88	29.091	28.910	28.730	28.550	28.371	28.192	28.014	27.835	27.658	27.480	179
.89	27.303	27.127	26.951	26.775	26.600	26.425	26.250	26.076	25.902	25.729	175
.90	25.556	25.383	25.211	25.039	24.867	24.696	24.525	24.355	24.185	24.015	171
.91	23.846	23.677	23.509	23.341	23.173	23.005	22.838	22.672	22.506	22.339	168
.92	22.174	22.009	21.844	21.679	21.515	21.351	21.188	21.025	20.862	20.700	164
.93	20.538	20.376	20.215	20.054	19.893	19.733	19.573	19.413	19.254	19.095	160
.94	18.936	18.778	18.620	18.462	18.305	18.148	17.991	17.835	17.679	17.524	157
.95	17.368	17.214	17.059	16.905	16.751	16.597	16.444	16.290	16.138	15.985	154
.96	15.833	15.682	15.530	15.379	15.228	15.078	14.928	14.778	14.628	14.479	150
.97	14.330	14.181	14.033	13.885	13.737	13.590	13.443	13.297	13.149	13.003	147
.98	12.857	12.712	12.566	12.421	12.276	12.132	11.988	11.844	11.700	11.557	144
.99	11.414	11.271	11.129	10.987	10.845	10.704	10.562	10.421	10.281	10.140	142
1.00	10.000										

See note, p. 29.

TABLE 23.—Specific gravities at $\frac{60^\circ}{60^\circ} F. \left(\frac{15^\circ 56}{15^\circ 56} C. \right)$ corresponding to degrees Baumé for liquids lighter than water

[Calculated from the formula, specific gravity $\frac{60^\circ F.}{60^\circ F.} = \frac{140}{130 + \text{Deg. Baumé}}]$

Degrees Baumé	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9964	0.9957	0.9950	0.9943	0.9936
11	.9929	.9922	.9915	.9908	.9901	.9894	.9887	.9880	.9873	.9866
12	.9859	.9852	.9845	.9838	.9831	.9825	.9818	.9811	.9804	.9797
13	.9790	.9783	.9777	.9770	.9763	.9756	.9749	.9743	.9736	.9729
14	.9722	.9715	.9709	.9702	.9695	.9689	.9682	.9675	.9669	.9662
15	.9655	.9649	.9642	.9635	.9629	.9622	.9615	.9609	.9602	.9596
16	.9589	.9582	.9576	.9569	.9563	.9556	.9550	.9543	.9537	.9530
17	.9524	.9517	.9511	.9504	.9498	.9492	.9485	.9479	.9472	.9466
18	.9459	.9453	.9447	.9440	.9434	.9428	.9421	.9415	.9409	.9402
19	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346	.9340
20	.9333	.9327	.9321	.9315	.9309	.9302	.9296	.9290	.9284	.9278
21	.9272	.9265	.9259	.9253	.9247	.9241	.9235	.9229	.9223	.9217
22	.9211	.9204	.9198	.9192	.9186	.9180	.9174	.9168	.9162	.9156
23	.9150	.9144	.9138	.9132	.9126	.9121	.9115	.9109	.9103	.9097
24	.9091	.9085	.9079	.9073	.9067	.9061	.9056	.9050	.9044	.9038
25	.9032	.9026	.9021	.9015	.9009	.9003	.8997	.8992	.8986	.8980
26	.8974	.8969	.8963	.8957	.8951	.8946	.8940	.8934	.8929	.8923
27	.8917	.8912	.8906	.8900	.8895	.8889	.8883	.8878	.8872	.8866
28	.8861	.8855	.8850	.8844	.8838	.8833	.8827	.8822	.8816	.8811
29	.8805	.8799	.8794	.8788	.8783	.8777	.8772	.8766	.8761	.8755
30	.8750	.8745	.8739	.8734	.8728	.8723	.8717	.8712	.8706	.8701
31	.8696	.8690	.8685	.8679	.8674	.8669	.8663	.8658	.8653	.8647
32	.8642	.8637	.8631	.8626	.8621	.8615	.8610	.8605	.8600	.8594
33	.8589	.8584	.8578	.8573	.8568	.8563	.8557	.8552	.8547	.8542
34	.8537	.8531	.8526	.8521	.8516	.8511	.8505	.8500	.8495	.8490
35	.8485	.8480	.8475	.8469	.8464	.8459	.8454	.8449	.8444	.8439
36	.8434	.8429	.8424	.8419	.8413	.8408	.8403	.8398	.8393	.8388
37	.8383	.8378	.8373	.8368	.8363	.8358	.8353	.8348	.8343	.8338
38	.8333	.8328	.8323	.8318	.8314	.8309	.8304	.8299	.8294	.8289
39	.8284	.8279	.8274	.8269	.8264	.8260	.8255	.8250	.8245	.8240
40	.8235	.8230	.8226	.8221	.8216	.8211	.8206	.8202	.8197	.8192
41	.8187	.8182	.8178	.8173	.8168	.8163	.8159	.8154	.8149	.8144
42	.8140	.8135	.8130	.8125	.8121	.8116	.8111	.8107	.8102	.8097
43	.8092	.8088	.8083	.8078	.8074	.8069	.8065	.8060	.8055	.8051
44	.8046	.8041	.8037	.8032	.8028	.8023	.8018	.8014	.8009	.8005
45	.8000	.7995	.7991	.7986	.7982	.7977	.7973	.7968	.7964	.7960
46	.7955	.7950	.7946	.7941	.7937	.7932	.7928	.7923	.7919	.7914
47	.7910	.7905	.7901	.7896	.7892	.7887	.7883	.7878	.7874	.7870
48	.7865	.7861	.7856	.7852	.7848	.7843	.7839	.7834	.7830	.7826
49	.7821	.7817	.7812	.7808	.7804	.7799	.7795	.7791	.7786	.7782
50	.7778	.7773	.7769	.7765	.7761	.7756	.7752	.7748	.7743	.7739
51	.7735	.7731	.7726	.7722	.7718	.7713	.7709	.7705	.7701	.7697
52	.7692	.7688	.7684	.7680	.7675	.7671	.7667	.7663	.7659	.7654
53	.7650	.7646	.7642	.7638	.7634	.7629	.7625	.7621	.7617	.7613
54	.7609	.7605	.7600	.7596	.7592	.7588	.7584	.7580	.7576	.7572
55	.7568	.7563	.7559	.7555	.7551	.7547	.7543	.7539	.7535	.7531

TABLE 23.—Specific gravities at $\frac{60^\circ}{60^\circ} F. \left(\frac{15^\circ 56}{15^\circ 56} C. \right)$ corresponding to degrees Baumé for liquids lighter than water—Continued

[Calculated from the formula, specific gravity $\frac{60^\circ}{60^\circ} F. = \frac{140}{130 + \text{Deg. Baumé}}]$

Degrees Baumé	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
55	0.7568	0.7563	0.7559	0.7555	0.7551	0.7547	0.7543	0.7539	0.7535	0.7531
56	.7527	.7523	.7519	.7515	.7511	.7507	.7503	.7499	.7495	.7491
57	.7487	.7483	.7479	.7475	.7471	.7467	.7463	.7459	.7455	.7451
58	.7447	.7443	.7439	.7435	.7431	.7427	.7423	.7419	.7415	.7411
59	.7407	.7403	.7400	.7396	.7392	.7388	.7384	.7380	.7376	.7372
60	.7368	.7365	.7361	.7357	.7353	.7349	.7345	.7341	.7338	.7334
61	.7330	.7326	.7322	.7318	.7315	.7311	.7307	.7303	.7299	.7295
62	.7292	.7288	.7284	.7280	.7277	.7273	.7269	.7265	.7261	.7258
63	.7254	.7250	.7246	.7243	.7239	.7235	.7231	.7228	.7224	.7220
64	.7216	.7213	.7209	.7205	.7202	.7198	.7194	.7191	.7187	.7183
65	.7179	.7176	.7172	.7168	.7165	.7161	.7157	.7154	.7150	.7147
66	.7143	.7139	.7136	.7132	.7128	.7125	.7121	.7117	.7114	.7110
67	.7107	.7103	.7099	.7096	.7092	.7089	.7085	.7081	.7078	.7074
68	.7071	.7067	.7064	.7060	.7056	.7053	.7049	.7046	.7042	.7039
69	.7035	.7032	.7028	.7025	.7021	.7018	.7014	.7011	.7007	.7004
70	.7000	.6997	.6993	.6990	.6986	.6983	.6979	.6976	.6972	.6969
71	.6965	.6962	.6958	.6955	.6951	.6948	.6944	.6941	.6938	.6934
72	.6931	.6927	.6924	.6920	.6917	.6914	.6910	.6907	.6903	.6900
73	.6897	.6893	.6890	.6886	.6883	.6880	.6876	.6873	.6869	.6866
74	.6863	.6859	.6856	.6853	.6849	.6846	.6843	.6839	.6836	.6833
75	.6829	.6826	.6823	.6819	.6816	.6813	.6809	.6806	.6803	.6799
76	.6796	.6793	.6790	.6786	.6783	.6780	.6776	.6773	.6770	.6767
77	.6763	.6760	.6757	.6753	.6750	.6747	.6744	.6740	.6737	.6734
78	.6731	.6728	.6724	.6721	.6718	.6715	.6711	.6708	.6705	.6702
79	.6699	.6695	.6692	.6689	.6686	.6683	.6679	.6676	.6673	.6670
80	.6667	.6663	.6660	.6657	.6654	.6651	.6648	.6645	.6641	.6638
81	.6635	.6632	.6629	.6626	.6623	.6619	.6616	.6613	.6610	.6607
82	.6604	.6601	.6598	.6594	.6591	.6588	.6585	.6582	.6579	.6576
83	.6573	.6570	.6567	.6564	.6560	.6557	.6554	.6551	.6548	.6545
84	.6542	.6539	.6536	.6533	.6530	.6527	.6524	.6521	.6518	.6515
85	.6512	.6509	.6506	.6503	.6500	.6497	.6494	.6490	.6487	.6484
86	.6482	.6479	.6476	.6473	.6470	.6467	.6464	.6461	.6458	.6455
87	.6452	.6449	.6446	.6443	.6440	.6437	.6434	.6431	.6428	.6425
88	.6422	.6419	.6416	.6413	.6410	.6407	.6404	.6401	.6399	.6396
89	.6393	.6390	.6387	.6384	.6381	.6378	.6375	.6372	.6369	.6367
90	.6364	.6361	.6358	.6355	.6352	.6349	.6346	.6343	.6341	.6338
91	.6335	.6332	.6329	.6326	.6323	.6321	.6318	.6315	.6312	.6309
92	.6306	.6303	.6301	.6298	.6295	.6292	.6289	.6286	.6284	.6281
93	.6278	.6275	.6272	.6270	.6267	.6264	.6261	.6258	.6256	.6253
94	.6250	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225
95	.6222	.6219	.6217	.6214	.6211	.6208	.6206	.6203	.6200	.6197
96	.6195	.6192	.6189	.6186	.6184	.6181	.6178	.6176	.6173	.6170
97	.6167	.6165	.6162	.6159	.6157	.6154	.6151	.6148	.6146	.6143
98	.6140	.6138	.6135	.6132	.6130	.6127	.6124	.6122	.6119	.6116
99	.6114	.6111	.6108	.6106	.6103	.6100	.6098	.6095	.6092	.6090
100	.6087	-----	-----	-----	-----	-----	-----	-----	-----	-----

See note, p. 29.

TABLE 24.—Degrees A. P. I.¹ corresponding to specific gravities at 60°/60° F.

$$\left(\frac{15.56}{15.56} C. \right)$$
[Calculated from the formula degrees A. P. I. = $\frac{141.5}{\text{specific gravity } 60^{\circ}/60^{\circ} \text{ F.}} - 131.5$]

Sp. gr. 60°/60° F.	0	1	2	3	4	5	6	7	8	9
0.60	104.33	103.94	103.55	103.16	102.77	102.38	102.00	101.61	101.23	100.85
.61	100.47	100.09	99.71	99.33	98.96	98.58	98.21	97.84	97.46	97.09
.62	96.73	96.36	95.99	95.63	95.26	94.90	94.54	94.18	93.82	93.46
.63	93.10	92.75	92.39	92.04	91.69	91.33	90.98	90.63	90.29	89.94
.64	89.59	89.25	88.90	88.56	88.22	87.88	87.54	87.20	86.86	86.53
.65	86.19	85.86	85.52	85.19	84.86	84.53	84.20	83.87	83.55	83.22
.66	82.89	82.57	82.25	81.92	81.60	81.28	80.96	80.64	80.33	80.01
.67	79.69	79.38	79.07	78.75	78.44	78.13	77.82	77.51	77.20	76.89
.68	76.69	76.38	75.98	75.67	75.37	75.07	74.77	74.47	74.17	73.87
.69	73.57	73.28	72.98	72.68	72.39	72.10	71.80	71.51	71.22	70.93
.70	70.64	70.35	70.07	69.78	69.49	69.21	68.92	68.64	68.36	68.08
.71	67.80	67.52	67.24	66.96	66.68	66.40	66.13	65.85	65.58	65.30
.72	65.08	64.76	64.48	64.21	63.94	63.67	63.40	63.14	62.87	62.60
.73	62.34	62.07	61.81	61.54	61.28	61.02	60.76	60.49	60.23	59.97
.74	59.72	59.46	59.20	58.94	58.69	58.43	58.18	57.92	57.67	57.42
.75	57.17	56.92	56.66	56.41	56.17	55.92	55.67	55.42	55.18	54.93
.76	54.68	54.44	54.20	53.95	53.71	53.47	53.23	52.98	52.74	52.51
.77	52.27	52.03	51.79	51.55	51.32	51.08	50.85	50.61	50.38	50.14
.78	49.91	49.68	49.45	49.22	48.98	48.75	48.53	48.30	48.07	47.84
.79	47.61	47.39	47.16	46.94	46.71	46.49	46.26	46.04	45.82	45.60
.80	45.38	45.15	44.93	44.71	44.49	44.28	44.06	43.84	43.62	43.41
.81	43.19	42.98	42.76	42.55	42.33	42.12	41.91	41.69	41.48	41.27
.82	41.06	40.85	40.64	40.43	40.22	40.02	39.81	39.60	39.39	39.19
.83	38.98	38.78	38.57	38.37	38.16	37.96	37.76	37.56	37.35	37.15
.84	36.95	36.75	36.55	36.35	36.15	35.95	35.76	35.56	35.36	35.17
.85	34.97	34.77	34.58	34.39	34.19	34.00	33.80	33.61	33.42	33.23
.86	33.03	32.84	32.65	32.46	32.27	32.08	31.89	31.71	31.52	31.33
.87	31.14	30.96	30.77	30.58	30.40	30.21	30.03	29.85	29.66	29.48
.88	29.30	29.11	28.93	28.75	28.57	28.39	28.21	28.03	27.85	27.67
.89	27.49	27.31	27.13	26.95	26.78	26.60	26.42	26.25	26.07	25.90
.90	25.72	25.55	25.37	25.20	25.03	24.85	24.68	24.51	24.34	24.17
.91	23.99	23.82	23.65	23.48	23.31	23.14	22.98	22.81	22.64	22.47
.92	22.30	22.14	21.97	21.80	21.64	21.47	21.31	21.14	20.98	20.81
.93	20.65	20.49	20.32	20.16	20.00	19.84	19.68	19.51	19.35	19.19
.94	19.08	18.87	18.71	18.55	18.39	18.24	18.08	17.92	17.76	17.60
.95	17.45	17.29	17.13	16.98	16.82	16.67	16.51	16.36	16.20	16.05
.96	15.90	15.74	15.59	15.44	15.28	15.13	14.98	14.83	14.68	14.53
.97	14.38	14.23	14.08	13.93	13.78	13.63	13.48	13.33	13.18	13.04
.98	12.89	12.74	12.69	12.45	12.30	12.15	12.01	11.86	11.72	11.57
.99	11.43	11.29	11.14	11.00	10.85	10.71	10.57	10.43	10.28	10.14
1.00	10.00	-----	-----	-----	-----	-----	-----	-----	-----	-----

¹ See note, p. 29.

TABLE 25.—Specific gravity at 60°/60° F. $\left(\frac{15.56}{15.56} C.\right)$ corresponding to degrees
A. P. I.¹

[Calculated from the formula, specific gravity $\frac{60^\circ}{60^\circ} F. = \frac{141.5}{131.5 + \text{degrees A. P. I.}}]$

Degrees A. P. I.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	.9993	.9986	.9979	.9972	.9965	.9958	.9951	.9944	.9937
11	.9930	.9923	.9916	.9909	.9902	.9895	.9888	.9881	.9874	.9868
12	.9861	.9854	.9847	.9840	.9833	.9826	.9820	.9813	.9806	.9799
13	.9792	.9786	.9779	.9772	.9765	.9759	.9752	.9745	.9738	.9732
14	.9725	.9718	.9712	.9705	.9698	.9692	.9685	.9679	.9672	.9665
15	.9659	.9652	.9646	.9639	.9632	.9626	.9619	.9613	.9606	.9600
16	.9593	.9587	.9580	.9574	.9567	.9561	.9554	.9548	.9541	.9535
17	.9529	.9522	.9516	.9509	.9503	.9497	.9490	.9484	.9478	.9471
18	.9465	.9459	.9452	.9446	.9440	.9433	.9427	.9421	.9415	.9408
19	.9402	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346
20	.9340	.9334	.9328	.9321	.9315	.9309	.9303	.9297	.9291	.9285
21	.9279	.9273	.9267	.9260	.9254	.9248	.9242	.9236	.9230	.9224
22	.9218	.9212	.9206	.9200	.9194	.9188	.9182	.9176	.9170	.9165
23	.9159	.9153	.9147	.9141	.9135	.9129	.9123	.9117	.9111	.9106
24	.9100	.9094	.9088	.9082	.9076	.9071	.9065	.9059	.9053	.9047
25	.9042	.9036	.9030	.9024	.9018	.9013	.9007	.9001	.8995	.8990
26	.8984	.8978	.8973	.8967	.8961	.8956	.8950	.8944	.8939	.8933
27	.8927	.8922	.8916	.8911	.8905	.8899	.8894	.8888	.8883	.8877
28	.8871	.8866	.8860	.8855	.8849	.8844	.8838	.8833	.8827	.8822
29	.8816	.8811	.8805	.8800	.8794	.8789	.8783	.8778	.8772	.8767
30	.8762	.8756	.8751	.8745	.8740	.8735	.8729	.8724	.8718	.8713
31	.8708	.8702	.8697	.8692	.8686	.8681	.8676	.8670	.8665	.8660
32	.8654	.8649	.8644	.8639	.8633	.8628	.8623	.8618	.8612	.8607
33	.8602	.8597	.8591	.8586	.8581	.8576	.8571	.8565	.8560	.8555
34	.8550	.8545	.8540	.8534	.8529	.8524	.8519	.8514	.8509	.8504
35	.8498	.8493	.8488	.8483	.8478	.8473	.8468	.8463	.8458	.8453
36	.8448	.8443	.8438	.8433	.8428	.8423	.8418	.8413	.8408	.8403
37	.8398	.8393	.8388	.8383	.8378	.8373	.8368	.8363	.8358	.8353
38	.8348	.8343	.8338	.8333	.8328	.8324	.8319	.8314	.8309	.8304
39	.8299	.8294	.8289	.8285	.8280	.8275	.8270	.8265	.8260	.8256
40	.8251	.8246	.8241	.8236	.8232	.8227	.8222	.8217	.8212	.8208
41	.8203	.8198	.8193	.8189	.8184	.8179	.8174	.8170	.8165	.8160
42	.8155	.8151	.8146	.8142	.8137	.8132	.8128	.8123	.8118	.8114
43	.8109	.8104	.8100	.8095	.8090	.8086	.8081	.8076	.8072	.8067
44	.8063	.8058	.8054	.8049	.8044	.8040	.8035	.8031	.8026	.8022
45	.8017	.8012	.8008	.8003	.7999	.7994	.7990	.7985	.7981	.7976
46	.7972	.7967	.7963	.7958	.7954	.7949	.7945	.7941	.7936	.7932
47	.7927	.7923	.7918	.7914	.7909	.7905	.7901	.7896	.7892	.7887
48	.7883	.7879	.7874	.7870	.7865	.7861	.7857	.7852	.7848	.7844
49	.7839	.7835	.7831	.7826	.7822	.7818	.7813	.7809	.7805	.7800
50	.7796	.7792	.7788	.7783	.7779	.7775	.7770	.7766	.7762	.7758
51	.7753	.7749	.7745	.7741	.7736	.7732	.7728	.7724	.7720	.7715
52	.7711	.7707	.7703	.7699	.7694	.7690	.7686	.7682	.7678	.7674
53	.7669	.7665	.7661	.7657	.7653	.7649	.7645	.7640	.7636	.7632
54	.7628	.7624	.7620	.7616	.7612	.7608	.7603	.7599	.7595	.7591

¹ See note, p. 29.

TABLE 25.—Specific gravity at 60°/60° F. ($\frac{15^{\circ}56}{15^{\circ}56}$ C.) corresponding to degrees

A. P. I.—Continued

[Calculated from the formula, specific gravity $\frac{60^{\circ}}{60^{\circ}} \text{ F.} = \frac{141.5}{131.5 + \text{degrees A. P. I.}}$]

Degrees A. P. I.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
55	.7587	.7583	.7579	.7575	.7571	.7567	.7563	.7559	.7555	.7551
56	.7547	.7543	.7539	.7535	.7531	.7527	.7523	.7519	.7515	.7511
57	.7507	.7503	.7499	.7495	.7491	.7487	.7483	.7479	.7475	.7471
58	.7467	.7463	.7459	.7455	.7451	.7447	.7443	.7440	.7436	.7432
59	.7428	.7424	.7420	.7416	.7412	.7408	.7405	.7401	.7397	.7393
60	.7389	.7385	.7381	.7377	.7374	.7370	.7366	.7362	.7358	.7354
61	.7351	.7347	.7343	.7339	.7335	.7332	.7328	.7324	.7320	.7316
62	.7313	.7309	.7305	.7301	.7298	.7294	.7290	.7286	.7283	.7279
63	.7275	.7271	.7268	.7264	.7260	.7256	.7253	.7249	.7245	.7242
64	.7238	.7234	.7230	.7227	.7223	.7219	.7216	.7212	.7208	.7205
65	.7201	.7197	.7194	.7190	.7186	.7183	.7179	.7175	.7172	.7168
66	.7165	.7161	.7157	.7154	.7150	.7146	.7143	.7139	.7136	.7132
67	.7128	.7125	.7121	.7118	.7114	.7111	.7107	.7103	.7100	.7096
68	.7093	.7089	.7086	.7082	.7079	.7075	.7071	.7068	.7064	.7061
69	.7057	.7054	.7050	.7047	.7043	.7040	.7036	.7033	.7029	.7026
70	.7022	.7019	.7015	.7012	.7008	.7005	.7001	.6998	.6995	.6991
71	.6988	.6984	.6981	.6977	.6974	.6970	.6967	.6964	.6960	.6957
72	.6953	.6950	.6946	.6943	.6940	.6936	.6933	.6929	.6926	.6923
73	.6919	.6916	.6913	.6909	.6906	.6902	.6899	.6896	.6892	.6889
74	.6886	.6882	.6879	.6876	.6872	.6869	.6866	.6862	.6859	.6856
75	.6852	.6849	.6846	.6842	.6839	.6836	.6832	.6829	.6826	.6823
76	.6819	.6816	.6813	.6809	.6806	.6803	.6800	.6796	.6793	.6790
77	.6787	.6783	.6780	.6777	.6774	.6770	.6767	.6764	.6761	.6757
78	.6754	.6751	.6748	.6745	.6741	.6738	.6735	.6732	.6728	.6725
79	.6722	.6719	.6716	.6713	.6709	.6706	.6703	.6700	.6697	.6693
80	.6690	.6687	.6684	.6681	.6678	.6675	.6671	.6668	.6665	.6662
81	.6659	.6656	.6653	.6649	.6646	.6643	.6640	.6637	.6634	.6631
82	.6628	.6625	.6621	.6618	.6615	.6612	.6609	.6606	.6603	.6600
83	.6597	.6594	.6591	.6588	.6584	.6581	.6578	.6575	.6572	.6569
84	.6566	.6563	.6560	.6557	.6554	.6551	.6548	.6545	.6542	.6539
85	.6536	.6533	.6530	.6527	.6524	.6521	.6518	.6515	.6512	.6509
86	.6506	.6503	.6500	.6497	.6494	.6491	.6488	.6485	.6482	.6479
87	.6476	.6473	.6470	.6467	.6464	.6461	.6458	.6455	.6452	.6449
88	.6446	.6444	.6441	.6438	.6435	.6432	.6429	.6426	.6423	.6420
89	.6417	.6414	.6411	.6409	.6406	.6403	.6400	.6397	.6394	.6391
90	.6388	.6385	.6382	.6380	.6377	.6374	.6371	.6368	.6365	.6362
91	.6360	.6357	.6354	.6351	.6348	.6345	.6342	.6340	.6337	.6334
92	.6331	.6328	.6325	.6323	.6320	.6317	.6314	.6311	.6309	.6306
93	.6303	.6300	.6297	.6294	.6292	.6289	.6286	.6283	.6281	.6278
94	.6275	.6272	.6269	.6267	.6264	.6261	.6258	.6256	.6253	.6250
95	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225	.6223
96	.6220	.6217	.6214	.6212	.6209	.6206	.6203	.6201	.6198	.6195
97	.6193	.6190	.6187	.6184	.6182	.6179	.6176	.6174	.6171	.6168
98	.6166	.6163	.6160	.6158	.6155	.6152	.6150	.6147	.6144	.6141
99	.6139	.6136	.6134	.6131	.6128	.6126	.6123	.6120	.6118	.6115
100	.6112									

TABLE 26.—*Specific gravity and weight per gallon of milk and cream*

[The specific gravities and weights per gallon given below are based on the values of specific gravity and coefficient of expansion determined by the Bureau of Standards and published in the Journ. Agric. Research, Vol. III, No. 3 (U. S. Department of Agriculture), Table II, p. 257]

Percentage of fat (by weight)	Specific gravity 20°/4° C.	Specific gravity 10°/4° C.	Pounds per gallon at 20° C. (68° F.)	Pounds per gallon at 10° C. (50° F.)
0.025	1.035	1.037	8.63	8.65
1	1.034	1.036	8.62	8.64
2	1.033	1.035	8.61	8.63
3	1.032	1.034	8.60	8.62
4	1.031	1.033	8.59	8.61
5	1.029	1.032	8.58	8.60
6	1.028	1.031	8.57	8.59
7	1.027	1.030	8.56	8.59
8	1.026	1.029	8.55	8.58
9	1.024	1.028	8.54	8.57
10	1.023	1.027	8.53	8.56
11	1.022	1.026	8.52	8.55
12	1.020	1.025	8.50	8.54
13	1.019	1.024	8.49	8.54
14	1.017	1.023	8.48	8.53
15	1.016	1.022	8.47	8.52
16	1.015	1.021	8.46	8.51
17	1.014	1.020	8.45	8.50
18	1.013	1.019	8.44	8.49
19	1.012	1.018	8.44	8.49
20	1.011	1.017	8.43	8.48
21	1.010	1.017	8.42	8.48
22	1.009	1.016	8.41	8.47
23	1.008	1.015	8.40	8.46
24	1.007	1.014	8.40	8.46
25	1.007	1.014	8.39	8.45
26	1.006	1.013	8.39	8.45
27	1.005	1.012	8.38	8.44
28	1.004	1.012	8.37	8.44
29	1.003	1.011	8.36	8.43
30	1.002	1.011	8.36	8.43
31	1.001	1.010	8.34	8.42
32	1.000	1.010	8.34	8.42
33	.999	1.009	8.33	8.41
34	.998	1.008	8.32	8.40
35	.998	1.008	8.31	8.40
36	.997	1.007	8.31	8.40
37	.996	1.007	8.30	8.39
38	.995	1.006	8.30	8.39
39	.994	1.005	8.29	8.38
40	.993	1.005	8.28	8.38

Specific gravity 20°/4° C. means the specific gravity at 20° C. (68° F.) in terms of water at its maximum density as unity, and specific gravity 10°/4° C. means the specific gravity at 10° C. (50° F.) in terms of the same unit. These specific gravity values are numerically the same as density at 20 and 10° C., respectively, in grams per milliliter.

NOTE.—The specific gravity at 20°/20° C. (68°/68° F.) corresponding to any percentage of fat can be obtained by dividing the specific gravity at 20°/4° C. by the density of water at 20° C. (0.9982343).

TABLE 27.—Volume¹ of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)

Percent- age of butter fat	Temperature (° F.)									
	50	60	70	80	90	100	110	120	130	140
	Volume									
0.025	0.9980	0.9990	1.0000	1.0015	1.0035	1.0060	1.0085	1.0110	1.0140	1.0175
1	.9980	.9990	1.0000	1.0015	1.0035	1.0060	1.0085	1.0110	1.0140	1.0175
2	.9975	.9990	1.0000	1.0020	1.0040	1.0060	1.0085	1.0115	1.0140	1.0175
3	.9975	.9990	1.0000	1.0020	1.0040	1.0065	1.0085	1.0115	1.0140	1.0175
4	.9975	.9985	1.0000	1.0020	1.0040	1.0065	1.0085	1.0115	1.0140	1.0175
5	.9975	.9985	1.0000	1.0020	1.0045	1.0065	1.0085	1.0115	1.0140	1.0175
6	.9970	.9985	1.0000	1.0020	1.0045	1.0065	1.0090	1.0115	1.0140	1.0175
7	.9970	.9985	1.0000	1.0025	1.0045	1.0070	1.0090	1.0120	1.0145	1.0175
8	.9970	.9985	1.0005	1.0025	1.0045	1.0070	1.0095	1.0120	1.0145	1.0175
9	.9965	.9985	1.0005	1.0025	1.0050	1.0070	1.0095	1.0120	1.0150	1.0180
10	.9965	.9985	1.0005	1.0025	1.0050	1.0075	1.0095	1.0120	1.0150	1.0180
11	.9965	.9985	1.0005	1.0025	1.0055	1.0075	1.0095	1.0120	1.0150	1.0180
12	.9965	.9980	1.0005	1.0030	1.0055	1.0080	1.0105	1.0130	1.0155	1.0180
13	.9965	.9980	1.0005	1.0030	1.0055	1.0080	1.0105	1.0130	1.0155	1.0180
14	.9960	.9980	1.0005	1.0030	1.0055	1.0085	1.0110	1.0135	1.0160	1.0185
15	.9960	.9980	1.0005	1.0030	1.0080	1.0085	1.0110	1.0135	1.0160	1.0185
16	.9960	.9980	1.0005	1.0035	1.0080	1.0090	1.0115	1.0140	1.0165	1.0190
17	.9945	.9980	1.0005	1.0035	1.0080	1.0090	1.0120	1.0145	1.0170	1.0190
18	.9940	.9980	1.0005	1.0035	1.0085	1.0095	1.0125	1.0150	1.0175	1.0195
19	.9940	.9975	1.0005	1.0035	1.0085	1.0095	1.0125	1.0150	1.0175	1.0195
20	.9930	.9975	1.0005	1.0035	1.0070	1.0100	1.0130	1.0155	1.0180	1.0205
21	.9930	.9975	1.0005	1.0040	1.0070	1.0100	1.0130	1.0160	1.0185	1.0205
22	.9930	.9975	1.0010	1.0040	1.0075	1.0105	1.0135	1.0165	1.0190	1.0210
23	.9930	.9975	1.0010	1.0040	1.0075	1.0105	1.0140	1.0165	1.0190	1.0210
24	.9925	.9975	1.0010	1.0040	1.0080	1.0110	1.0145	1.0170	1.0200	1.0220
25	.9925	.9970	1.0010	1.0045	1.0080	1.0115	1.0145	1.0175	1.0200	1.0225
26	.9925	.9970	1.0010	1.0045	1.0085	1.0120	1.0155	1.0185	1.0210	1.0235
27	.9925	.9970	1.0010	1.0045	1.0085	1.0120	1.0155	1.0185	1.0210	1.0235
28	.9915	.9965	1.0010	1.0045	1.0090	1.0125	1.0160	1.0190	1.0220	1.0245
29	.9915	.9965	1.0010	1.0050	1.0090	1.0130	1.0160	1.0195	1.0220	1.0245
30	.9915	.9965	1.0010	1.0050	1.0095	1.0130	1.0165	1.0195	1.0220	1.0250
31	.9915	.9965	1.0010	1.0050	1.0095	1.0135	1.0170	1.0200	1.0225	1.0250
32	.9910	.9960	1.0010	1.0055	1.0100	1.0135	1.0170	1.0205	1.0230	1.0255
33	.9910	.9960	1.0010	1.0055	1.0100	1.0140	1.0170	1.0205	1.0230	1.0255
34	.9910	.9960	1.0010	1.0055	1.0105	1.0140	1.0175	1.0210	1.0240	1.0260
35	.9900	.9960	1.0010	1.0060	1.0105	1.0145	1.0180	1.0210	1.0240	1.0260
36	.9900	.9955	1.0010	1.0060	1.0110	1.0145	1.0185	1.0215	1.0245	1.0270
37	.9890	.9955	1.0010	1.0060	1.0110	1.0150	1.0185	1.0215	1.0245	1.0270
38	.9890	.9955	1.0010	1.0065	1.0115	1.0155	1.0190	1.0220	1.0250	1.0280
39	.9890	.9955	1.0010	1.0065	1.0115	1.0160	1.0195	1.0225	1.0255	1.0280
40	.9890	.9950	1.0010	1.0065	1.0115	1.0165	1.0200	1.0235	1.0265	1.0290

¹ The tabulated values are given to the nearest 0.0005.

TABLE 28.—Conversion of density basis

Prepared for use in reducing readings of a hydrometer graduated to indicate density or specific gravity at a specified standard temperature, T , referred to water at a specified temperature, T' , as unity, to the basis of another standard temperature, t , and reference temperature, t' .

The factor Δ (given in units of the sixth decimal place), multiplied by the density or specific-gravity reading, gives the correction to be applied to the reading to reduce it to the required basis.

Suppose a hydrometer indicates specific gravity at $\frac{20^\circ}{4^\circ}$ C., and it is required to know the correction in order that it shall indicate specific gravity at $\frac{15.56}{15.56}$ C., then,

$$D_{\frac{15.56}{15.56}} = D_{\frac{20^\circ}{4^\circ}} + \Delta D_{\frac{20^\circ}{4^\circ}}$$

That is, if the hydrometer indicates correctly a specific gravity of 1.5760 at $\frac{20^\circ}{4^\circ}$, then at $\frac{15.56}{15.56}$ the reading of the instrument will be too low by $1.5760 \times 0.001062 = 0.0017$. A correction of 0.0017 must therefore be added to the indication of the hydrometer.

Or, if a maker using standards indicating $D_{\frac{20^\circ}{4^\circ}}$ C. wishes to graduate a hydrometer to indicate density at $\frac{15.56}{15.56}$ C. referred to water at $\frac{15.56}{15.56}$ C. ($D_{\frac{15.56}{15.56}}$ C.) the readings of the standard must be corrected as follows:

Suppose the standard correct at $\frac{20^\circ}{4^\circ}$ C. reads 1.5760
The correction to be applied is +.0017

Corresponding reading on instrument to be correct at $\frac{15.56}{15.56}$ C. is 1.5777

The table is calculated for Jena 16^{mm} glass.

Given basis of density	Required basis of density $\frac{t}{t'}$									
	$D_{\frac{25^\circ}{4^\circ}}$ C.	$D_{\frac{20}{4}}$	$D_{\frac{17.5}{4}}$	$D_{\frac{15.56}{4}}$	$D_{\frac{15}{4}}$	$D_{\frac{15}{15}}$	$D_{\frac{15.56}{15.56}}$	$D_{\frac{17.5}{17.5}}$	$D_{\frac{20}{20}}$	$D_{\frac{25}{25}}$
$\frac{T}{T'}$	Δ (In units of the sixth decimal place)									
$D_{\frac{25^\circ}{4^\circ}}$ C.	0	+115	+172	+217	+230	+1104	+1177	+1459	+1884	+2931
$D_{\frac{20}{4}}$	-115	0	+58	+102	+115	+989	+1062	+1345	+1769	+2816
$D_{\frac{17.5}{4}}$	-172	-58	0	+45	+58	+932	+1005	+1287	+1711	+2758
$D_{\frac{15.56}{4}}$	-217	-102	-45	0	+13	+887	+960	+1242	+1667	+2713
$D_{\frac{15}{4}}$	-230	-115	-58	-13	0	+874	+947	+1229	+1654	+2700
$D_{\frac{15}{15}}$	-1103	-989	-931	-886	-873	0	+73	+354	+779	+1826
$D_{\frac{15.56}{15.56}}$	-1176	-1061	-1004	-960	-947	-73	0	+281	+706	+1752
$D_{\frac{17.5}{17.5}}$	-1457	-1343	-1285	-1240	-1227	-354	-281	0	+424	+1471
$D_{\frac{20}{20}}$	-1881	-1766	-1708	-1664	-1651	-778	-706	-423	0	+1046
$D_{\frac{25}{25}}$	-2923	-2808	-2751	-2707	-2694	-1821	-1748	-1468	-1044	0

NOTE.—This table can not be used to make changes of density basis involving the expansion of liquids other than water.

TABLE 29.—Weight (in grams), at various pressures and temperatures, of 1 liter of dry air containing 0.04 per cent of CO₂

[Computed from the formula $C = \frac{1.293052}{1 + 0.00367t} \times \frac{h}{760}$, where h is pressure in mm of mercury at 0° C., and standard gravity, and t is temperature in degrees centigrade]

Temperature in Deg. C.	Pressure in mm of Hg (0° C., standard gravity)											
	720	725	730	735	740	745	750	755	760	765	770	775
15	1.1611	1.1691	1.1772	1.1853	1.1933	1.2014	1.2095	1.2175	1.2256	1.2336	1.2417	1.2498
16	1.1571	1.1651	1.1731	1.1812	1.1892	1.1972	1.2053	1.2133	1.2213	1.2294	1.2374	1.2454
17	1.1531	1.1611	1.1691	1.1771	1.1851	1.1931	1.2011	1.2091	1.2171	1.2251	1.2331	1.2411
18	1.1491	1.1571	1.1650	1.1730	1.1810	1.1890	1.1970	1.2049	1.2129	1.2209	1.2289	1.2369
19	1.1451	1.1531	1.1611	1.1690	1.1770	1.1849	1.1929	1.2008	1.2088	1.2167	1.2247	1.2326
20	1.1412	1.1492	1.1571	1.1650	1.1729	1.1809	1.1888	1.1967	1.2046	1.2126	1.2205	1.2284
21	1.1373	1.1452	1.1531	1.1610	1.1689	1.1768	1.1847	1.1926	1.2005	1.2084	1.2163	1.2242
22	1.1335	1.1414	1.1492	1.1571	1.1650	1.1728	1.1807	1.1886	1.1965	1.2043	1.2122	1.2201
23	1.1296	1.1375	1.1453	1.1532	1.1610	1.1689	1.1767	1.1846	1.1924	1.2002	1.2081	1.2160
24	1.1258	1.1337	1.1415	1.1493	1.1571	1.1649	1.1727	1.1806	1.1884	1.1962	1.2040	1.2118
25	1.1220	1.1298	1.1376	1.1454	1.1532	1.1610	1.1688	1.1766	1.1844	1.1922	1.2000	1.2078
26	1.1183	1.1261	1.1338	1.1416	1.1494	1.1571	1.1649	1.1727	1.1804	1.1882	1.1959	1.2037
27	1.1146	1.1223	1.1300	1.1378	1.1455	1.1533	1.1610	1.1687	1.1765	1.1842	1.1920	1.1997
28	1.1108	1.1186	1.1263	1.1340	1.1417	1.1494	1.1571	1.1648	1.1725	1.1803	1.1880	1.1957
29	1.1072	1.1149	1.1225	1.1302	1.1379	1.1456	1.1533	1.1610	1.1687	1.1764	1.1840	1.1917
30	1.1035	1.1112	1.1188	1.1265	1.1342	1.1418	1.1495	1.1571	1.1648	1.1725	1.1801	1.1878
31	1.0999	1.1075	1.1151	1.1228	1.1304	1.1381	1.1457	1.1533	1.1610	1.1686	1.1762	1.1839

TABLE 30.—Buoyancy constants (mg/ml)

[Difference in milligrams between the mass and the apparent weight of 1 milliliter of water weighed with brass weights ($d=8.4$) in air at various temperatures and barometer readings (unreduced). A humidity of 50 per cent saturation is assumed. To find the weight of 1 milliliter of air under the conditions assumed in this table, multiply the buoyancy constant by 1.135 (42/37)]

Pressure	Temperature in degrees centigrade			
	15	20	25	30
640	0.904	0.886	0.869	0.852
650	.918	.900	.883	.866
660	.932	.914	.897	.879
670	.946	.928	.911	.893
680	.960	.942	.924	.906
690	.975	.956	.938	.920
700	.989	.970	.952	.933
705	.996	.977	.958	.940
710	1.003	.984	.965	.947
715	1.010	.991	.972	.953
720	1.017	.998	.979	.960
725	1.024	1.004	.985	.967
730	1.031	1.011	.992	.973
735	1.038	1.018	.999	.980
740	1.045	1.025	1.006	.987
745	1.052	1.032	1.013	.994
750	1.059	1.039	1.020	1.000
755	1.067	1.046	1.027	1.007
760	1.074	1.053	1.034	1.014
765	1.081	1.060	1.040	1.020
770	1.088	1.067	1.047	1.027
775	1.095	1.074	1.054	1.034
780	1.102	1.081	1.061	1.041

TABLE 31.—Density (in grams per milliliter) of water at temperatures from 0 to 102° C.¹

Temperature, °C.	Density	Temperature, °C.	Density	Temperature, °C.	Density
0	0. 99987	35	0. 99406	70	0. 97781
1	. 99993	36	. 99371	71	. 97723
2	. 99997	37	. 99336	72	. 97666
3	. 99999	38	. 99299	73	. 97607
4	1. 00000	39	. 99262	74	. 97548
5	. 99999	40	. 99224	75	. 97489
6	. 99997	41	. 99186	76	. 97428
7	. 99993	42	. 99147	77	. 97368
8	. 99988	43	. 99107	78	. 97307
9	. 99981	44	. 99066	79	. 97245
10	. 99973	45	. 99024	80	. 97183
11	. 99963	46	. 98982	81	. 97120
12	. 99952	47	. 98940	82	. 97057
13	. 99940	48	. 98896	83	. 96994
14	. 99927	49	. 98852	84	. 96930
15	. 99913	50	. 98807	85	. 96865
16	. 99897	51	. 98762	86	. 96800
17	. 99880	52	. 98715	87	. 96734
18	. 99862	53	. 98669	88	. 96668
19	. 99843	54	. 98621	89	. 96601
20	. 99823	55	. 98573	90	. 96534
21	. 99802	56	. 98524	91	. 96467
22	. 99780	57	. 98478	92	. 96399
23	. 99756	58	. 98425	93	. 96330
24	. 99732	59	. 98375	94	. 96261
25	. 99707	60	. 98324	95	. 96192
26	. 99681	61	. 98272	96	. 96122
27	. 99654	62	. 98220	97	. 96051
28	. 99626	63	. 98167	98	. 95981
29	. 99597	64	. 98113	99	. 95909
30	. 99567	65	. 98059	100	. 95838
31	. 99537	66	. 98005	101	. 95765
32	. 99505	67	. 97950	102	. 95693
33	. 99473	68	. 97894		
34	. 99440	69	. 97838		
35	. 99406	70	. 97781		

According to M. Thiesen, *Wiss. Abh. der Physikalisch-Technischen Reichsanstalt*, 4, No. 1; 1904.

TABLE 32.—Density of pure water free from air

[Under standard pressure (76 cm), at every tenth part of a degree of the international hydrogen scale from 0 to 41° C. in grams per milliliter.]

[*Indicates change in first two decimal places. See next line, column 0]

De- grees centi- grade	Tenths of degrees										Mean differ- ences	
	0	1	2	3	4	5	6	7	8	9		
0	0.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59	
1		9267	9315	9363	9408	9452	9494	9534	9573	9610	+ 41	
2		9679	9711	9741	9769	9796	9821	9844	9866	9887	+ 24	
3		9922	9937	9951	9962	9973	9981	9988	9994	9998	+ 8	
4	1.000 0000	*9999	*9996	*9992	*9986	*9979	*9970	*9960	*9947	*9934	— 8	
5	.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	— 24	
6		9682	9650	9617	9582	9545	9507	9468	9427	9385	— 39	
7		9296	9249	9201	9151	9100	9048	8994	8938	8881	— 53	
8		8764	8703	8641	8577	8512	8445	8377	8308	8237	— 67	
9		8691	8617	8540	8463	8384	8303	8222	8139	8055	— 81	
10		7282	7194	7105	7014	6921	6826	6729	6632	6533	— 95	
11		6331	6228	6124	6020	5913	5805	5696	5586	5474	— 108	
12		5248	5132	5016	4898	4780	4660	4538	4415	4291	— 121	
13		4040	3912	3784	3654	3523	3391	3257	3122	2986	— 133	
14		2712	2572	2431	2289	2147	2003	1858	1711	1564	— 146	
15		1268	1114	0962	0809	0655	0499	0343	0185	0026	*9865	— 156
16	.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	8031	— 168
17		8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	— 178
18		6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	— 190
19		4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	— 200
20		2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	— 211
21		0233	0016	*9799	*9580	*9359	*9139	*8917	*8694	*8470	*8245	— 221
22	.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	5703	— 232
23		5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	— 242
24		3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	— 252
25		0770	0513	0255	*9997	*9736	*9476	*9214	*8951	*8688	*8423	— 261
26	.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	5451	— 271
27		5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	— 280
28		2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	— 289
29	.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	6783	— 298
30		6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	— 307
31		3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	— 315
32		0861	0241	*9920	*9699	*9476	*9254	*9030	*8804	*8579	*8353	— 324
33	.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	4008	— 332
34		4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	— 340
35		0610	0267	*9922	*9676	*9430	*9183	*8934	*8683	*8431	*8178	— 347
36	.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	3585	— 355
37		3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	— 362
38	.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	6263	— 370
39		6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	— 377
40		2497	2116	1734	1352	0971	0587	0203	*9618	*9433	*9047	— 384
41	.991 8661											

¹According to P. Chappuis, Bureau International des Poids et Mesures, Travaux et Mémoires, XIII, 1907.

105396°—24†—4

TABLE 33.—Weight of 1 gallon of water

[This table is based on the water densities of P. Chappuis (Bureau International des Poids et Mesures. Travaux et Mémoires, XIII; 1907) for 0 to 40° C., and of M. Thiesen (Wiss. Abb. der Physikalisch-Technischen Reichsanstalt, 4, No. 1; 1904) for 41 to 100° C. The weights in air are for dry air at the same temperature as the water up to 40° C. and at a (corrected) barometric pressure of 760 mm and against brass weights of 8.4 density at 0° C. Above 40° C. the temperature of the air is assumed to be 20° C., i. e., the water is allowed to cool to 20° C. before the weighings are made. The volumetric computations are based on the relation that 1 liter = 1.000027 cubic decimeters and 1 cubic decimeter = 61.023378 cubic inches. The weights corresponding to 15° C. (60° F.) and 16½° C. (62° F.) have been included in the table because of the frequent use of these temperatures in engineering and industrial work]

Temperature, °C.	Weight in vacuo		Weight in air	
	Grams	Pounds	Grams	Pounds
0	3784.833	8.34412	3780.520	8.33461
1	5.055	.34461	0.756	.33613
2	5.211	.34495	0.930	.33551
3	5.303	.34515	1.037	.33575
4	5.332	.34522	1.062	.33585
5	5.302	.34515	1.067	.33582
6	5.212	.34495	0.992	.33565
7	5.066	.34463	0.861	.33536
8	4.864	.34419	0.675	.33495
9	4.610	.34363	0.435	.33442
10	4.303	.34295	0.144	.33378
11	3.943	.34216	3779.798	.33302
12	3.534	.34125	9.403	.33215
13	3.076	.34025	8.960	.33117
14	2.574	.33914	8.472	.33009
15	2.026	.33793	7.939	.32892
(15½) 60° F.	(3781.703)	(8.33722)	(3777.623)	(8.32823)
16	1.435	.33663	7.362	.32765
(16½) 62° F.	(3781.017)	(8.33571)	(3776.953)	(8.32675)
17	0.801	.33523	6.741	.32628
18	0.125	.33374	6.060	.32482
19	3779.407	.33216	5.375	.32327
20	8.649	.33049	4.630	.32162
21	7.850	.32872	3.845	.31989
22	7.012	.32688	3.021	.31806
23	6.135	.32494	2.157	.31617
24	5.220	.32293	1.256	.31419
25	4.268	.32083	0.317	.31212
26	3.279	.31865	3769.341	.30996
27	2.254	.31639	8.329	.30773
28	1.195	.31405	7.283	.30543
29	0.100	.31164	6.201	.30304
30	3768.972	.30915	5.086	.30058
31	7.812	.30659	3.938	.29805
32	6.618	.30396	2.757	.29545
33	5.393	.30126	1.545	.29278
34	4.137	.29849	0.301	.29003
35	2.851	.29566	3759.027	.28723
36	1.536	.29276	7.725	.28436
37	0.192	.28979	6.393	.28142
38	3758.820	.28677	5.033	.27842
39	7.420	.28368	3.645	.27536
40	5.995	.28054	2.232	.27225
41	4.52	.2773	0.53	.2685
42	3.04	.2740	3749.05	.2652
43	1.53	.2707	7.54	.2619
44	3749.98	.2673	5.99	.2585
45	8.39	.2638	4.40	.2550
46	6.80	.2603	2.81	.2515
47	5.21	.2568	1.23	.2480
48	3.54	.2531	3739.56	.2443
49	1.88	.2494	7.90	.2407

TABLE 33.—Weight of 1 gallon of water—Continued

Temperature, C.	Weight in vacuo		Weight in air	
	Grams	Pounds	Grams	Pounds
50	3740.17	8.2457	3736.20	8.2369
51	3738.47	.2419	4.50	.2332
52	6.69	.2380	2.72	.2292
53	4.95	.2341	0.98	.2254
54	3.13	.2301	3729.16	.2214
55	1.32	.2261	7.35	.2174
56	3729.46	.2220	5.50	.2133
57	7.72	.2182	3.76	.2095
58	5.71	.2138	1.75	.2051
59	3.82	.2096	3719.86	.2009
60	1.89	.2054	7.93	.1966
61	3719.92	.2010	5.97	.1923
62	7.95	.1967	4.00	.1880
63	5.95	.1923	2.00	.1835
64	3.90	.1877	3709.96	.1790
65	1.86	.1832	7.91	.1745
66	3709.82	.1787	5.87	.1700
67	7.73	.1741	3.79	.1655
68	5.61	.1695	1.67	.1608
69	3.49	.1648	3699.56	.1561
70	1.33	.1600	7.40	.1514
71	3699.14	.1552	5.21	.1465
72	6.98	.1504	3.05	.1418
73	4.75	.1455	0.82	.1369
74	2.52	.1406	3688.59	.1319
75	0.28	.1357	6.36	.1270
76	3687.97	.1306	4.05	.1219
77	5.70	.1256	1.78	.1169
78	3.39	.1205	3679.48	.1119
79	1.05	.1153	7.13	.1067
80	3678.70	.1101	4.79	.1015
81	6.32	.1049	2.41	.0963
82	3.93	.0996	0.02	.0910
83	1.54	.0944	3667.64	.0858
84	3669.12	.0890	5.22	.0804
85	6.66	.0836	2.76	.0750
86	4.20	.0782	0.31	.0696
87	1.70	.0727	3657.81	.0641
88	3659.21	.0672	5.31	.0586
89	6.67	.0616	2.78	.0530
90	4.13	.0560	0.25	.0474
91	1.60	.0504	3647.71	.0418
92	3649.02	.0447	5.14	.0362
93	6.41	.0390	2.53	.0304
94	3.80	.0332	3639.92	.0247
95	1.19	.0274	7.32	.0189
96	3638.54	.0216	4.67	.0131
97	5.85	.0157	1.98	.0072
98	3.20	.0098	3629.34	.0013
99	0.47	.0038	6.61	7.9953
100	3627.79	7.9979	3.93	.9894

TABLE 34.—Weight of 1 cubic foot of water

[This table is based on the water densities of P. Chappuis (Bureau International des Poids et Mesures, Travaux et Mémoires, XIII: 1907) for 0 to 40° C. and of M. Thiesen (Wiss. Abh. der Physikalisch-Technischen Reichsanstalt, 4, No. 1; 1904) for 41 to 100° C. The weights in air are for dry air at the same temperature as the water up to 40° C. and at a (corrected) barometric pressure of 760 mm and against brass weights of 8.4 density at 0° C. Above 40° C. the temperature of the air is assumed to be 20° C., i. e., the water is allowed to cool to 20° C. before the weighings are made. The volumetric computations are based on the relation that 1 liter = 1.000027 cubic decimeters and 1 cubic decimeter = 61.023378 cubic inches. The weights corresponding to 15½° C. (60° F.) and 16¼° C. (62° F.) have been included in the table because of the frequent use of these temperatures in engineering and industrial work]

Temperature, °C.	Weight in vacuo		Weight in air	
	Grams	Pounds	Grams	Pounds
0	28312.517	62.4183	28280.254	62.3472
1	14.178	.4220	82.033	.3511
2	15.345	.4246	83.321	.3540
3	16.033	.4261	84.121	.3557
4	16.250	.4266	84.458	.3565
5	16.025	.4261	84.345	.3562
6	15.352	.4246	83.784	.3550
7	14.280	.4222	82.804	.3528
8	12.749	.4189	81.413	.3498
9	10.849	.4147	79.618	.3458
10	08.552	.4096	77.441	.3410
11	05.859	.4037	74.853	.3353
12	02.800	.3969	71.898	.3288
13	28299.374	.3894	68.584	.3215
14	95.619	.3811	64.933	.3134
15	91.519	.3720	60.946	.3046
(15½) 60° F.	(28289.103)	(62.3667)	(28258.58)	(62.2994)
16	87.098	.3623	56.630	.2951
(16¼) 62° F.	(28283.971)	(62.3554)	(28253.57)	(62.2884)
17	82.356	.3518	51.965	.2849
18	77.299	.3407	47.040	.2740
19	71.928	.3289	41.766	.2624
20	66.258	.3164	36.193	.2501
21	60.281	.3032	30.321	.2371
22	54.012	.2894	24.157	.2235
23	47.452	.2749	17.694	.2098
24	40.607	.2598	10.954	.1944
25	33.485	.2441	03.930	.1789
26	26.067	.2278	28196.629	.1629
27	18.420	.2109	89.059	.1462
28	10.500	.1934	81.234	.1289
29	02.307	.1754	73.140	.1111
30	28193.869	.1568	64.799	.0927
31	85.191	.1376	56.212	.0737
32	76.259	.1179	47.377	.0543
33	67.096	.0977	38.311	.0343
34	57.700	.0770	29.005	.0138
35	48.080	.0558	19.475	61.9926
36	38.243	.0341	09.735	.9713
37	28.190	.0120	28099.771	.9493
38	17.926	61.9863	89.596	.9269
39	07.454	.9663	79.215	.9040
40	28096.794	.9428	68.645	.8807
41	85.76	.919	55.90	.853
42	74.71	.894	44.66	.828
43	63.39	.869	33.55	.803
44	51.78	.844	21.94	.778

TABLE 34.—Weight of 1 cubic foot of water—Continued

Temperature, °C.	Weight in vacuo		Weight in air	
	Grams	Pounds	Grams	Pounds
45	28039.88	61.817	28010.06	61.782
46	28.00	.791	27998.19	.778
47	16.10	.785	84.31	.699
48	03.64	.737	73.86	.672
49	27991.18	.710	61.42	.644
50	78.44	.682	48.69	.616
51	65.70	.654	35.96	.588
52	52.39	.624	22.67	.559
53	39.37	.596	09.65	.530
54	25.77	.566	27894.08	.500
55	12.18	.536	82.50	.470
56	27898.31	.505	69.64	.440
57	85.28	.476	55.63	.411
58	70.27	.443	40.63	.378
59	56.12	.412	26.49	.347
60	41.67	.380	12.06	.315
61	26.95	.348	27797.36	.283
62	12.22	.315	82.65	.250
63	27797.21	.282	67.66	.217
64	81.92	.249	52.38	.184
65	66.63	.215	37.11	.150
66	51.34	.181	21.63	.116
67	35.77	.147	06.27	.082
68	19.91	.112	27690.44	.047
69	04.06	.077	74.89	.012
70	27697.92	.041	58.47	60.976
71	71.49	.005	42.07	.940
72	55.35	60.970	25.95	.905
73	38.64	.933	09.25	.868
74	21.94	.896	27592.57	.831
75	05.22	.859	75.88	.794
76	27597.96	.821	58.62	.756
77	70.97	.784	41.65	.719
78	53.69	.745	24.29	.681
79	36.14	.707	08.86	.642
80	18.56	.668	27499.22	.604
81	00.75	.629	71.50	.564
82	27492.90	.589	53.08	.525
83	65.06	.550	35.86	.486
84	46.95	.510	17.76	.446
85	28.54	.470	27399.27	.406
86	10.12	.429	80.99	.365
87	27391.44	.388	62.31	.324
88	72.75	.347	43.65	.282
89	53.78	.305	24.70	.241
90	34.61	.263	06.74	.199
91	15.84	.221	27294.80	.157
92	27296.58	.179	67.56	.116
93	77.06	.138	48.06	.072
94	57.51	.093	28.62	.029
95	37.97	.049	09.01	69.996
96	18.15	.005	27199.29	.942
97	27194.96	69.961	69.12	.896
98	78.22	.916	49.23	.854
99	57.93	.872	28.98	.809
100	37.73	.828	08.87	.766

TABLE 35.—*Apparent weight (in grams) of water in air*

[This table gives the apparent weight, for temperatures between 15 and 30° C., humidity 50 per cent, unreduced barometer reading 76 cm of certain volumes of water weighed with brass weights. This table is based on the data given in Tables 30 and 32, and may be conveniently employed to determine definite volumes of water for calibrating instruments. The table assumes the air to be at the same temperature as the water.]

Temp. in degrees C.	2,000 ml	1,000 ml	500 ml	400 ml	300 ml	250 ml	150 ml
15	1, 996. 11	998. 05	499. 03	399. 22	299. 42	249. 51	149. 71
16	1, 995. 80	997. 90	498. 95	399. 16	299. 37	249. 48	149. 68
17	1, 995. 48	997. 74	498. 87	399. 10	299. 32	249. 43	149. 66
18	1, 995. 13	997. 56	498. 78	399. 03	299. 27	249. 39	149. 63
19	1, 994. 76	997. 38	498. 69	398. 95	299. 21	259. 34	149. 61
20	1, 994. 36	997. 18	498. 59	398. 87	299. 15	249. 30	149. 58
21	1, 993. 95	996. 97	498. 49	398. 79	299. 09	249. 24	149. 55
22	1, 993. 51	996. 76	498. 38	398. 70	299. 03	249. 19	149. 51
23	1, 993. 06	996. 53	498. 26	398. 61	298. 96	249. 13	149. 48
24	1, 992. 58	996. 29	498. 15	398. 52	298. 89	249. 07	149. 44
25	1, 992. 09	996. 04	498. 02	398. 42	298. 81	249. 01	149. 41
26	1, 991. 57	995. 79	497. 89	398. 31	298. 74	248. 95	149. 37
27	1, 991. 04	995. 52	497. 76	398. 21	298. 66	248. 88	149. 33
28	1, 990. 49	995. 24	497. 62	398. 10	298. 57	248. 81	149. 29
29	1, 989. 92	994. 96	497. 48	397. 98	298. 49	248. 74	149. 24
30	1, 989. 33	994. 66	497. 33	397. 87	298. 40	248. 67	149. 20

TABLE 36.—*Temperature correction for glass volumetric apparatus*

[This table gives the correction to be added to actual capacity (determined at certain temperatures) to give the capacity at the standard temperature, 20° C. Conversely, by subtracting the corrections from the indicated capacity of an instrument standard at 20° C. the corresponding capacity at other temperatures is obtained. The table assumes for the cubical coefficient of expansion of glass 0.000025 per degree centigrade. The coefficients of expansion of glasses used for volumetric instruments vary from 0.000023 to 0.000028.]

Temp. in degrees C.	2,000 ml	1,000 ml	500 ml	400 ml	300 ml	250 ml
15	+0. 25	+0. 12	+0. 06	+0. 05	+0. 04	+0. 031
16	+ . 20	+ . 10	+ . 05	+ . 04	+ . 03	+ . 025
17	+ . 15	+ . 08	+ . 04	+ . 03	+ . 02	+ . 019
18	+ . 10	+ . 05	+ . 02	+ . 02	+ . 02	+ . 012
19	+ . 05	+ . 02	+ . 01	+ . 01	+ . 01	+ . 006
21	— . 05	— . 02	— . 01	— . 01	— . 01	— . 006
22	— . 10	— . 05	— . 02	— . 02	— . 02	— . 012
23	— . 15	— . 08	— . 04	— . 03	— . 02	— . 019
24	— . 20	— . 10	— . 05	— . 04	— . 03	— . 025
25	— . 25	— . 12	— . 06	— . 05	— . 04	— . 031
26	— . 30	— . 15	— . 08	— . 06	— . 04	— . 038
27	— . 35	— . 18	— . 09	— . 07	— . 05	— . 044
28	— . 40	— . 20	— . 10	— . 08	— . 06	— . 050
29	— . 45	— . 22	— . 11	— . 09	— . 07	— . 056
30	— . 50	— . 25	— . 12	— . 10	— . 08	— . 062

TABLE 37.—*Apparent weight (in grams) of water in air*

[This table gives the apparent weight of certain volumes of water weighed against brass weights in air, humidity 50 per cent, barometer reading 76 cm (unreduced), weighings being made at 20° C., the water and air being at the same temperature. It differs from Table 30 only in its greater temperature range and in the fact that the water is allowed to come to a temperature of 20° C. before the weighings are made. The weighings may be made at any temperature between 18 and 22° without introducing errors greater than 1 mg. per 100 cc.]

Temp. in de- grees C.	2,000 ml	1,000 ml	500 ml	400 ml	300 ml	250 ml	150 ml
15	1, 996. 14	998. 07	499. 04	399. 23	299. 42	249. 52	149. 71
16	1, 995. 83	997. 92	498. 96	399. 17	299. 38	249. 48	149. 69
17	1, 995. 50	997. 75	498. 87	399. 10	299. 32	249. 44	149. 66
18	1, 995. 14	997. 57	498. 79	399. 03	299. 27	249. 39	149. 64
19	1, 994. 76	997. 38	498. 69	398. 95	299. 21	249. 35	149. 61
20	1, 994. 36	997. 18	498. 59	398. 87	299. 15	249. 30	149. 58
21	1, 993. 94	996. 97	498. 49	398. 79	299. 09	249. 24	149. 55
22	1, 993. 50	996. 75	498. 37	398. 70	299. 02	249. 19	149. 51
23	1, 993. 04	996. 52	498. 26	398. 61	298. 96	249. 13	149. 48
24	1, 992. 55	996. 28	498. 14	398. 51	298. 88	249. 07	149. 44
25	1, 992. 05	996. 03	498. 01	398. 41	298. 81	249. 01	149. 40
26	1, 991. 53	995. 76	497. 88	398. 31	298. 73	248. 94	149. 36
27	1, 990. 99	995. 49	497. 75	398. 20	298. 65	248. 87	149. 32
28	1, 990. 43	995. 21	497. 61	398. 09	298. 56	248. 80	149. 28
29	1, 989. 85	994. 93	497. 46	397. 97	298. 48	248. 73	149. 24
30	1, 989. 26	994. 63	497. 31	397. 85	298. 39	248. 66	149. 19
35	1, 986. 02	993. 01	496. 51	397. 20	297. 90	248. 25	148. 95
40	1, 982. 41	991. 20	495. 60	396. 48	297. 36	247. 80	148. 68
45	1, 978. 4	989. 2	494. 6	395. 7	296. 8	247. 3	148. 4
50	1, 974. 1	987. 0	493. 5	394. 8	296. 1	246. 8	148. 1
55	1, 969. 4	984. 7	492. 3	393. 9	295. 4	246. 2	147. 7
60	1, 964. 4	982. 2	491. 1	392. 9	294. 7	245. 6	147. 3
65	1, 959. 1	979. 6	489. 8	391. 8	293. 9	244. 9	146. 9
70	1, 953. 6	976. 8	488. 4	390. 7	293. 0	244. 2	146. 5
75	1, 947. 7	973. 9	486. 9	389. 5	292. 2	243. 5	146. 1
80	1, 941. 6	970. 8	485. 4	388. 3	291. 2	242. 7	145. 6
85	1, 935. 3	967. 6	483. 8	387. 1	290. 3	241. 9	145. 1
90	1, 928. 6	964. 3	482. 2	385. 7	289. 3	241. 1	144. 6
95	1, 921. 8	960. 9	480. 5	384. 4	288. 3	240. 2	144. 1
100	1, 914. 7	957. 4	478. 7	382. 9	287. 2	239. 3	143. 6

TABLE 38.—*Temperature correction for volumetric solutions*

[This table gives the correction to various observed volumes of water, measured at the designated temperatures, to give the volume at the standard temperature, 20° C. Conversely, by subtracting the corrections from the volume desired at 20° C., the volume that must be measured out at the designated temperatures in order to give the desired volume at 20° C., will be obtained. It is assumed that the volumes are measured in glass apparatus having a coefficient of cubical expansion of 0.000025 per degree centigrade. The table is applicable to dilute aqueous solutions having the same coefficient of expansion as water]

Temperature of measurement, °C.	Capacity of apparatus in milliliters at 20° C.						
	2,000	1,000	500	400	300	250	150
	Correction in milliliters to give volume of water at 20° C.						
15	+1.54	+0.77	+0.38	+0.31	+0.23	+0.19	+0.12
16	+1.28	+.64	+.32	+.26	+.19	+.16	+.10
17	+.99	+.50	+.25	+.20	+.15	+.12	+.07
18	+.68	+.34	+.17	+.14	+.10	+.08	+.05
19	+.35	+.18	+.09	+.07	+.05	+.04	+.03
21	-.37	-.18	-.09	-.07	-.06	-.05	-.03
22	-.77	-.38	-.19	-.15	-.12	-.10	-.06
23	-1.18	-.59	-.30	-.24	-.18	-.15	-.09
24	-1.61	-.81	-.40	-.32	-.24	-.20	-.12
25	-2.07	-1.03	-.52	-.41	-.31	-.26	-.15
26	-2.54	-1.27	-.64	-.51	-.38	-.32	-.19
27	-3.03	-1.52	-.76	-.61	-.46	-.38	-.23
28	-3.55	-1.77	-.89	-.71	-.53	-.44	-.27
29	-4.08	-2.04	-1.02	-.82	-.61	-.51	-.31
30	-4.62	-2.31	-1.16	-.92	-.69	-.58	-.35

In using the above table to correct the volume of certain standard solutions to 20° C. more accurate results will be obtained if the numerical values of the corrections are increased by the percentages given below:

Solution	Normality		
	N	N/2	N/10
HNO ₃	50	25	6
H ₂ SO ₄	45	25	5
NaOH.....	40	25	5
KOH.....	40	20	4

TABLE 39.—Reduction of weighings to vacuo

The weight of a body in vacuo is determined by adding to its apparent weight in air a buoyancy correction equal to the weight of the air displaced by the difference in volume of the body weighed and the weights required to balance it on an equal arm balance.

$$M = W + \rho \left(\frac{M}{d_1} - \frac{W}{d_2} \right) = W \frac{d_1}{d_2} \left(\frac{d_2 - \rho}{d_1 - \rho} \right) = W \frac{d_1}{d_1 - \rho} \left(1 - \frac{\rho}{d_2} \right) =$$

$$W \left[1 + \frac{\rho}{d_2} \left(\frac{d_2 - d_1}{d_1 - \rho} \right) \right] = W + k W / 1,000$$

M = weight in vacuo; W = apparent weight in air; ρ = density of air; d_1 = density of body; d_2 = density of weights.

The following table has been computed for $\rho = 0.0012$:

Density of body weighed g/cm ³	Correction factor, k			Density of body weighed, g/cm ³	Correction factor, k		
	Pt. Ir. weights d = 21.5 g/cm ³	Brass weights 8.4	Quartz or Al. Wts. 2.65		Pt. Ir. weights d = 21.5 g/cm ³	Brass weights 8.4	Quartz or Al. Wts. 2.65
0.5	+2.35	+2.26	+1.95	5.0	+0.18	+0.10	-0.21
.6	+1.95	+1.86	+1.55	6.0	+0.15	+0.06	-.25
.7	+1.66	+1.57	+1.26	7.0	+0.12	+0.03	-.28
.8	+1.45	+1.36	+1.05	8.0	+0.10	+0.01	-.30
.9	+1.28	+1.19	+.88	9.0	+0.08	-.01	-.32
1.0	+1.14	+1.05	+.75	10.0	+0.06	-.02	-.33
1.1	+1.04	+.95	+.64	11.0	+0.05	-.03	-.34
1.2	+.94	+.86	+.55	12.0	+0.04	-.04	-.35
1.3	+.87	+.78	+.47	13.0	+0.04	-.05	-.36
1.4	+.80	+.72	+.40	14.0	+0.03	-.06	-.37
1.5	+.74	+.66	+.35	15.0	+0.02	-.06	-.37
1.6	+.69	+.61	+.30	16.0	+0.02	-.07	-.38
1.7	+.65	+.56	+.26	17.0	+0.01	-.07	-.38
1.8	+.61	+.52	+.21	18.0	+0.01	-.08	-.39
1.9	+.58	+.49	+.18	19.0	+0.01	-.08	-.39
2.0	+.54	+.46	+.15	20.0	.00	-.08	-.39
2.5	+.42	+.34	+.03	21.0	.00	-.09	-.40
3.0	+.34	+.26	-.05	22.0	.00	-.09	-.40
3.5	+.29	+.20	-.11	23.0	.00	-.09	-.40
4.0	+.24	+.16	-.15	24.0	-.01	-.09	-.40

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES
OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR**

Tables 35 to 47 are intended for the calculation of capacities of glass vessels of common sizes from the weight (in air) of the water contained or delivered. They give for each nominal capacity and observed temperature the amounts to be added to the apparent weight (in air against brass weights) of the water contained in or delivered by a glass vessel to give the capacity in milliliters at 20° C. They are calculated on the following data assumed as approximating ordinary conditions:

Observed barometric pressure..... 76 cm
 Relative humidity..... 50 per cent
 Coefficient of expansion of glass..... 0.000025 per ° C.

EXAMPLE OF USE OF TABLE

Determination of capacity of glass measuring flask marked "To contain 250 ml at 20° C."

Apparent weight of water at the observed temperature 22°3 C 249.198 g
 From Table 40, correction..... .813

 Actual capacity at 20°..... 250.011 ml

TABLE 40.—*Indicated capacity 250 ml*

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C.]

Temperature in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.518	0.521	0.524	0.528	0.530	0.534	0.537	0.540	0.543	0.546
16	.550	.554	.556	.560	.563	.567	.570	.574	.578	.581
17	.584	.588	.592	.596	.599	.603	.606	.610	.614	.618
18	.622	.626	.630	.633	.638	.642	.646	.649	.654	.658
19	.662	.666	.670	.674	.679	.683	.687	.692	.696	.700
20	.705	.709	.714	.718	.722	.727	.732	.736	.741	.746
21	.750	.754	.760	.764	.769	.774	.778	.784	.788	.793
22	.798	.804	.808	.813	.818	.824	.828	.834	.839	.844
23	.849	.854	.860	.865	.870	.875	.881	.886	.892	.897
24	.902	.908	.913	.919	.924	.930	.936	.941	.947	.952
25	.958	.964	.969	.975	.981	.986	.993	.998	1.004	1.010
26	1.016	1.022	1.028	1.034	1.040	1.046	1.052	1.058	1.064	1.070
27	1.076	1.082	1.089	1.095	1.101	1.108	1.114	1.120	1.126	1.132
28	1.139	1.146	1.152	1.158	1.165	1.172	1.178	1.184	1.191	1.198
29	1.204	1.211	1.218							

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES
OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Contd.**

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C.]

TABLE 41.—Indicated capacity 200 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.414	0.417	0.419	0.422	0.424	0.427	0.430	0.432	0.435	0.437
16	.440	.443	.445	.448	.451	.454	.456	.459	.462	.465
17	.468	.470	.473	.477	.479	.482	.485	.488	.491	.494
18	.497	.501	.504	.507	.510	.513	.516	.519	.523	.526
19	.529	.533	.536	.540	.543	.546	.550	.553	.557	.560
20	.564	.567	.571	.574	.578	.582	.585	.589	.593	.596
21	.600	.604	.608	.612	.615	.619	.623	.627	.631	.635
22	.639	.643	.647	.650	.655	.659	.663	.667	.671	.675
23	.679	.683	.688	.692	.696	.700	.705	.709	.713	.717
24	.722	.726	.731	.735	.739	.744	.748	.753	.757	.762
25	.766	.771	.775	.780	.785	.789	.794	.799	.803	.808
26	.813	.818	.822	.827	.832	.837	.842	.846	.851	.856
27	.861	.866	.871	.876	.881	.886	.891	.896	.901	.906
28	.911	.917	.922	.927	.932	.937	.942	.947	.953	.958
29	.963	.969	.974							

TABLE 42.—Indicated capacity 150 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.311	0.313	0.314	0.316	0.318	0.320	0.322	0.324	0.326	0.328
16	.330	.332	.334	.336	.338	.340	.342	.344	.346	.349
17	.351	.353	.355	.357	.359	.362	.364	.366	.368	.371
18	.373	.375	.378	.380	.383	.385	.387	.390	.392	.395
19	.397	.400	.402	.405	.408	.410	.412	.415	.418	.420
20	.423	.425	.428	.431	.433	.436	.439	.442	.445	.448
21	.450	.453	.456	.459	.461	.464	.467	.470	.473	.476
22	.479	.483	.485	.488	.491	.494	.497	.500	.503	.506
23	.509	.512	.516	.519	.522	.525	.529	.532	.535	.538
24	.541	.545	.548	.551	.554	.558	.562	.565	.568	.571
25	.575	.578	.581	.585	.588	.592	.596	.599	.602	.606
26	.610	.613	.617	.620	.624	.628	.631	.635	.638	.642
27	.645	.649	.653	.657	.661	.664	.668	.672	.676	.680
28	.684	.688	.691	.695	.699	.703	.707	.711	.715	.719
29	.722	.726	.730							

TABLE 43.—Indicated capacity 100 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.207	0.208	0.210	0.211	0.212	0.213	0.215	0.216	0.217	0.219
16	.220	.221	.223	.224	.225	.227	.228	.230	.231	.232
17	.234	.235	.237	.238	.240	.241	.243	.244	.246	.247
18	.249	.250	.252	.253	.255	.257	.258	.260	.261	.263
19	.265	.266	.268	.270	.272	.273	.275	.277	.278	.280
20	.282	.284	.285	.287	.289	.291	.293	.294	.296	.298
21	.300	.302	.304	.306	.308	.310	.312	.314	.315	.317
22	.319	.321	.323	.325	.327	.329	.331	.333	.336	.338
23	.340	.342	.344	.346	.348	.350	.352	.354	.357	.359
24	.361	.363	.365	.368	.370	.372	.374	.376	.379	.381
25	.383	.386	.388	.390	.392	.395	.397	.399	.402	.404
26	.406	.409	.411	.414	.416	.418	.421	.423	.426	.428
27	.431	.433	.436	.438	.440	.443	.446	.448	.451	.453
28	.456	.458	.461	.463	.466	.469	.471	.474	.476	.479
29	.482	.484	.487							

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES
OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Contd.**

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C.]

TABLE 44.—Indicated capacity 90 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.186	0.188	0.189	0.190	0.191	0.192	0.193	0.194	0.196	0.197
16	.198	.199	.200	.202	.203	.204	.205	.207	.208	.209
17	.210	.212	.213	.214	.216	.217	.218	.220	.221	.222
18	.224	.225	.227	.228	.230	.231	.232	.234	.235	.237
19	.238	.240	.241	.243	.244	.246	.247	.249	.251	.252
20	.254	.255	.257	.258	.260	.262	.263	.265	.267	.268
21	.270	.272	.273	.275	.277	.278	.280	.282	.284	.286
22	.287	.289	.291	.293	.295	.296	.298	.300	.302	.304
23	.306	.308	.309	.311	.313	.315	.317	.319	.321	.323
24	.325	.327	.329	.331	.333	.335	.337	.339	.341	.343
25	.345	.347	.349	.351	.353	.355	.357	.359	.362	.364
26	.366	.368	.370	.372	.374	.377	.379	.381	.383	.385
27	.388	.390	.392	.394	.396	.399	.401	.403	.406	.408
28	.410	.412	.415	.417	.419	.422	.424	.426	.429	.431
29	.434	.436	.438							

TABLE 45.—Indicated capacity 80 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.166	0.167	0.168	0.169	0.170	0.171	0.172	0.173	0.174	0.175
16	.176	.177	.178	.179	.180	.181	.183	.184	.185	.186
17	.187	.188	.189	.191	.192	.193	.194	.195	.196	.198
18	.199	.200	.201	.203	.204	.205	.206	.208	.209	.210
19	.212	.213	.214	.216	.217	.218	.220	.221	.222	.224
20	.226	.227	.228	.230	.231	.233	.234	.236	.237	.239
21	.240	.241	.243	.245	.246	.248	.249	.251	.252	.254
22	.255	.257	.259	.260	.262	.264	.265	.267	.268	.270
23	.272	.273	.275	.277	.278	.280	.282	.284	.285	.287
24	.289	.290	.292	.294	.296	.298	.299	.301	.303	.306
25	.306	.308	.310	.312	.314	.316	.318	.320	.321	.323
26	.325	.327	.329	.331	.333	.335	.337	.339	.341	.342
27	.344	.346	.348	.350	.352	.354	.356	.358	.360	.362
28	.365	.367	.369	.371	.373	.375	.377	.379	.381	.383
29	.385	.387	.390							

TABLE 46.—Indicated capacity 70 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.145	0.146	0.147	0.148	0.148	0.149	0.150	0.151	0.152	0.153
16	.154	.155	.156	.157	.158	.159	.160	.161	.162	.163
17	.164	.165	.166	.167	.168	.169	.170	.171	.172	.173
18	.174	.175	.176	.177	.178	.180	.181	.182	.183	.184
19	.185	.186	.188	.189	.190	.191	.192	.194	.195	.196
20	.197	.199	.200	.201	.202	.204	.205	.206	.207	.209
21	.210	.211	.213	.214	.216	.217	.218	.220	.221	.222
22	.224	.225	.226	.228	.229	.230	.232	.233	.235	.236
23	.238	.239	.241	.242	.244	.245	.247	.248	.250	.251
24	.253	.254	.256	.257	.259	.260	.262	.263	.265	.267
25	.268	.270	.271	.273	.274	.276	.278	.280	.281	.283
26	.284	.286	.288	.289	.291	.293	.294	.296	.298	.299
27	.301	.303	.305	.307	.308	.310	.312	.314	.315	.317
28	.319	.321	.323	.324	.326	.328	.330	.332	.333	.335
29	.337	.339	.341							

TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Contd.

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters.]

TABLE 47.—Indicated capacity 60 ml

Temperature in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.124	0.125	0.126	0.127	0.127	0.128	0.129	0.130	0.130	0.131
16	.132	.133	.134	.134	.135	.136	.137	.138	.139	.140
17	.140	.141	.142	.143	.144	.145	.146	.147	.147	.148
18	.149	.150	.151	.152	.153	.154	.155	.156	.157	.158
19	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
20	.169	.170	.171	.172	.173	.175	.176	.177	.178	.179
21	.180	.181	.182	.183	.185	.186	.187	.188	.189	.190
22	.192	.193	.194	.195	.196	.198	.199	.200	.201	.202
23	.204	.205	.206	.208	.209	.210	.211	.213	.214	.215
24	.216	.218	.219	.220	.222	.223	.225	.226	.227	.228
25	.230	.231	.232	.234	.235	.237	.238	.240	.241	.242
26	.244	.245	.247	.248	.250	.251	.253	.254	.255	.257
27	.258	.260	.261	.263	.264	.266	.267	.269	.270	.272
28	.273	.275	.276	.278	.280	.281	.283	.284	.286	.288
29	.289	.291	.292							

TABLE 48.—Indicated capacity 50 ml

Temperature in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.104	0.104	0.105	0.106	0.106	0.107	0.107	0.108	0.109	0.109
16	.110	.111	.111	.112	.113	.113	.114	.115	.116	.116
17	.117	.118	.118	.119	.120	.121	.121	.122	.123	.124
18	.124	.125	.126	.127	.128	.128	.129	.130	.131	.132
19	.132	.133	.134	.135	.136	.137	.137	.138	.139	.140
20	.141	.142	.143	.144	.144	.145	.146	.147	.148	.149
21	.150	.151	.152	.153	.154	.155	.156	.157	.158	.159
22	.160	.161	.162	.163	.164	.165	.166	.167	.168	.169
23	.170	.171	.172	.173	.174	.175	.176	.177	.178	.179
24	.180	.182	.183	.184	.185	.186	.187	.188	.189	.190
25	.192	.193	.194	.195	.196	.197	.199	.200	.201	.202
26	.203	.204	.206	.207	.208	.209	.210	.212	.213	.214
27	.215	.216	.218	.219	.220	.222	.223	.224	.225	.226
28	.228	.229	.230	.232	.233	.234	.236	.237	.238	.240
29	.241	.242	.244							

TABLE 49.—Indicated capacity 45 ml

Temperature in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.093	0.094	0.094	0.095	0.095	0.096	0.097	0.097	0.098	0.098
16	.099	.100	.100	.101	.101	.102	.103	.103	.104	.105
17	.105	.106	.107	.107	.108	.108	.109	.110	.111	.111
18	.112	.113	.113	.114	.115	.115	.116	.117	.118	.118
19	.119	.120	.121	.121	.122	.123	.124	.124	.125	.126
20	.127	.128	.128	.129	.130	.131	.132	.132	.133	.134
21	.135	.136	.137	.138	.138	.139	.140	.141	.142	.143
22	.144	.145	.145	.146	.147	.148	.149	.150	.151	.152
23	.153	.154	.155	.156	.157	.158	.159	.160	.160	.161
24	.162	.163	.164	.165	.166	.167	.168	.169	.170	.171
25	.172	.173	.174	.176	.177	.178	.179	.180	.181	.182
26	.183	.184	.185	.186	.187	.188	.189	.190	.192	.193
27	.194	.195	.196	.197	.198	.199	.201	.202	.203	.204
28	.205	.206	.207	.209	.210	.211	.212	.213	.214	.216
29	.217	.218	.219							

**TABLES OF CORRECTIONS FOR DETERMINING THE TRUE CAPACITIES
OF GLASS VESSELS FROM THE WEIGHT OF WATER IN AIR—Contd.**

[Amounts to be added to apparent weight of water in grams to obtain actual capacity in milliliters at 20° C.]

TABLE 50.—Indicated capacity 40 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.083	0.083	0.084	0.084	0.085	0.085	0.086	0.086	0.087	0.087
16	.088	.089	.089	.090	.090	.091	.091	.092	.092	.093
17	.094	.094	.095	.095	.096	.096	.097	.098	.098	.099
18	.099	.100	.101	.101	.102	.102	.103	.104	.105	.105
19	.106	.107	.107	.108	.109	.109	.110	.111	.111	.112
20	.113	.113	.114	.115	.116	.116	.117	.118	.119	.119
21	.120	.121	.122	.122	.123	.124	.125	.125	.126	.127
22	.128	.129	.129	.130	.131	.132	.133	.133	.134	.135
23	.136	.137	.138	.138	.139	.140	.141	.142	.143	.143
24	.144	.145	.146	.147	.148	.149	.150	.151	.151	.152
25	.153	.154	.155	.156	.157	.158	.159	.160	.161	.162
26	.163	.164	.164	.165	.166	.167	.168	.169	.170	.171
27	.172	.173	.174	.175	.176	.177	.178	.179	.180	.181
28	.182	.183	.184	.185	.186	.187	.188	.189	.191	.192
29	.193	.194	.195							

TABLE 51.—Indicated capacity 35 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.073	0.073	0.073	0.074	0.074	0.075	.075	0.076	0.076	0.076
16	.077	.078	.078	.078	.079	.079	.080	.080	.081	.081
17	.082	.082	.083	.083	.084	.084	.085	.085	.086	.086
18	.087	.088	.088	.089	.089	.090	.090	.091	.091	.092
19	.092	.093	.094	.094	.095	.096	.096	.097	.097	.098
20	.099	.099	.100	.100	.101	.102	.102	.103	.104	.104
21	.105	.106	.106	.107	.108	.108	.109	.110	.110	.111
22	.112	.113	.113	.114	.115	.115	.116	.117	.117	.118
23	.119	.120	.120	.121	.122	.122	.123	.124	.125	.126
24	.126	.127	.128	.129	.129	.130	.131	.132	.133	.133
25	.134	.135	.136	.137	.137	.138	.139	.140	.141	.141
26	.142	.143	.144	.145	.146	.146	.147	.148	.149	.150
27	.151	.152	.152	.153	.154	.155	.156	.157	.158	.159
28	.159	.160	.161	.162	.163	.164	.165	.166	.167	.168
29	.169	.170	.170							

TABLE 52.—Indicated capacity 30 ml

Tempera- ture in degrees C.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
15	0.062	0.063	0.063	0.063	0.064	0.064	0.064	0.065	0.065	0.066
16	.066	.066	.067	.067	.068	.068	.068	.069	.069	.070
17	.070	.071	.071	.071	.072	.072	.073	.073	.074	.074
18	.075	.075	.076	.076	.077	.077	.078	.077	.078	.079
19	.079	.080	.080	.081	.081	.082	.082	.083	.084	.084
20	.085	.085	.086	.086	.087	.087	.088	.088	.089	.089
21	.090	.091	.091	.092	.092	.093	.093	.094	.094	.095
22	.096	.096	.097	.098	.098	.099	.099	.100	.101	.101
23	.102	.103	.103	.104	.104	.105	.106	.106	.107	.108
24	.108	.109	.110	.110	.111	.112	.112	.113	.114	.114
25	.115	.116	.116	.117	.118	.118	.119	.120	.121	.121
26	.122	.123	.123	.124	.125	.126	.126	.127	.128	.128
27	.129	.130	.131	.131	.132	.133	.134	.134	.135	.136
28	.137	.137	.138	.139	.140	.141	.141	.142	.143	.144
29	.145	.145	.146							

MASTER SCALES FOR THE GRADUATION OF HYDROMETERS

The accompanying tables were prepared for the use of hydrometer makers in the graduation of hydrometer scales to indicate percentages of ethyl alcohol by weight at 20° C or by volume at 60° F, and they give the proportional length of any part of the hydrometer scale, assuming that the entire scale has a length of 1000 mm.¹ and that the hydrometer stem is of uniform cross section. For example, if it is required to construct a hydrometer scale having a certain range the spacing of the graduations of the scale should be made proportional to the differences of the lengths shown in the table for that range.

These tables were prepared from the alcoholometric tables published in this circular (Tables 2 and 3). The original work on which the tables are based is described in detail in the Bulletin of the Bureau of Standards, vol. 9, p. 328 (Reprint No. 197). The indications of hydrometers graduated in accordance with these master scales will be on the basis officially adopted by the Bureau of Standards. Hydrometers may also be graduated to indicate percentages of "proof spirit," according to the official tables of the United States Bureau of Internal Revenue (adopted 1913), by the use of the accompanying master scale intended for the graduation of hydrometers to indicate percentages of alcohol by volume at 60° F. The percentage of proof spirit is in every case twice the percentage of alcohol by volume. For example, 25 per cent alcohol by volume is equivalent to 50 per cent proof spirit; 50 per cent alcohol by volume is equivalent to 100 per cent proof spirit. The spacing of the graduations for proof spirit hydrometers can, therefore, be taken directly from Table 54, the per cent alcohol by volume being multiplied by 2 in each case to give the equivalent per cent proof spirit.

¹ Any other convenient unit may be employed; the tabulated lengths will then be in that unit.

TABLE 53.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by weight at 80° C.

[Total length of scale 1,000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
0.0	0.00	5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45
.1	.71	.1	34.40	.1	63.51	.1	90.00	.1	115.99
.2	1.42	.2	35.02	.2	64.06	.2	90.50	.2	116.53
.3	2.13	.3	35.64	.3	64.61	.3	91.00	.3	117.07
.4	2.84	.4	36.26	.4	65.16	.4	91.50	.4	117.61
.5	3.55	.5	36.87	.5	65.71	.5	91.99	.5	118.15
.6	4.26	.6	37.48	.6	66.26	.6	92.48	.6	118.69
.7	4.97	.7	38.08	.7	66.81	.7	92.98	.7	119.23
.8	5.68	.8	38.68	.8	67.36	.8	93.48	.8	119.78
.9	6.38	.9	39.28	.9	67.91	.9	93.98	.9	120.33
1.0	7.08	6.0	39.88	11.0	68.45	16.0	94.49	21.0	120.88
.1	7.78	.1	40.48	.1	68.99	.1	95.00	.1	121.43
.2	8.48	.2	41.08	.2	69.53	.2	95.51	.2	121.98
.3	9.18	.3	41.68	.3	70.07	.3	96.02	.3	122.53
.4	9.88	.4	42.28	.4	70.61	.4	96.53	.4	123.08
.5	10.58	.5	42.88	.5	71.15	.5	97.04	.5	123.63
.6	11.28	.6	43.47	.6	71.69	.6	97.55	.6	124.18
.7	11.97	.7	44.06	.7	72.23	.7	98.06	.7	124.73
.8	12.66	.8	44.65	.8	72.77	.8	98.57	.8	125.28
.9	13.35	.9	45.24	.9	73.31	.9	99.08	.9	125.83
2.0	14.04	7.0	45.82	12.0	73.84	17.0	99.60	22.0	126.38
.1	14.73	.1	46.40	.1	74.37	.1	100.12	.1	126.94
.2	15.42	.2	46.98	.2	74.90	.2	100.64	.2	127.50
.3	16.11	.3	47.56	.3	75.43	.3	101.16	.3	128.06
.4	16.80	.4	48.14	.4	75.96	.4	101.68	.4	128.62
.5	17.49	.5	48.72	.5	76.49	.5	102.20	.5	129.19
.6	18.18	.6	49.30	.6	77.02	.6	102.72	.6	129.76
.7	18.87	.7	49.88	.7	77.55	.7	103.24	.7	130.33
.8	19.55	.8	50.46	.8	78.08	.8	103.76	.8	130.90
.9	20.22	.9	51.04	.9	78.61	.9	104.28	.9	131.47
3.0	20.89	8.0	51.62	13.0	79.13	18.0	104.80	23.0	132.04
.1	21.56	.1	52.19	.1	79.65	.1	105.32	.1	132.61
.2	22.22	.2	52.76	.2	80.17	.2	105.85	.2	133.18
.3	22.88	.3	53.33	.3	80.69	.3	106.38	.3	133.75
.4	23.54	.4	53.90	.4	81.21	.4	106.91	.4	134.32
.5	24.20	.5	54.47	.5	81.73	.5	107.44	.5	134.89
.6	24.85	.6	55.04	.6	82.25	.6	107.97	.6	135.46
.7	25.50	.7	55.61	.7	82.77	.7	108.50	.7	136.03
.8	26.15	.8	56.18	.8	83.29	.8	109.03	.8	136.60
.9	26.80	.9	56.75	.9	83.81	.9	109.56	.9	137.18
4.0	27.45	9.0	57.32	14.0	84.33	19.0	110.09	24.0	137.76
.1	28.09	.1	57.89	.1	84.85	.1	110.62	.1	138.34
.2	28.73	.2	58.46	.2	85.37	.2	111.15	.2	138.92
.3	29.37	.3	59.03	.3	85.89	.3	111.68	.3	139.50
.4	30.01	.4	59.60	.4	86.41	.4	112.21	.4	140.09
.5	30.64	.5	60.17	.5	86.93	.5	112.75	.5	140.68
.6	31.27	.6	60.73	.6	87.45	.6	113.29	.6	141.27
.7	31.90	.7	61.29	.7	87.97	.7	113.83	.7	141.86
.8	32.53	.8	61.85	.8	88.49	.8	114.37	.8	142.45
.9	33.16	.9	62.41	.9	89.00	.9	114.91	.9	143.04
5.0	33.78	10.0	62.96	15.0	89.50	20.0	115.45	25.0	143.63

TABLE 53.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	143.63	30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41
.1	144.22	.1	176.63	.1	213.88	.1	255.62	.1	301.85
.2	144.82	.2	177.33	.2	214.67	.2	256.50	.2	302.29
.3	145.42	.3	178.03	.3	215.46	.3	257.38	.3	303.23
.4	146.02	.4	178.73	.4	216.26	.4	258.26	.4	304.17
.5	146.62	.5	179.43	.5	217.06	.5	259.14	.5	305.12
.6	147.23	.6	180.13	.6	217.86	.6	260.02	.6	306.07
.7	147.84	.7	180.84	.7	218.66	.7	260.90	.7	307.02
.8	148.45	.8	181.55	.8	219.46	.8	261.79	.8	307.97
.9	149.06	.9	182.26	.9	220.26	.9	262.68	.9	308.92
26.0	149.67	31.0	182.97	36.0	221.06	41.0	263.57	46.0	309.88
.1	150.28	.1	183.68	.1	221.86	.1	264.46	.1	310.84
.2	150.90	.2	184.40	.2	222.67	.2	265.35	.2	311.80
.3	151.52	.3	185.12	.3	223.48	.3	266.24	.3	312.76
.4	152.14	.4	185.85	.4	224.29	.4	267.14	.4	313.72
.5	152.77	.5	186.58	.5	225.10	.5	268.04	.5	314.68
.6	153.40	.6	187.31	.6	225.91	.6	268.94	.6	315.64
.7	154.03	.7	188.04	.7	226.73	.7	269.84	.7	316.60
.8	154.66	.8	188.77	.8	227.55	.8	270.74	.8	317.56
.9	155.29	.9	189.51	.9	228.37	.9	271.64	.9	318.52
27.0	155.93	32.0	190.25	37.0	229.19	42.0	272.55	47.0	319.49
.1	156.57	.1	190.99	.1	230.01	.1	273.46	.1	320.46
.2	157.21	.2	191.73	.2	230.84	.2	274.37	.2	321.43
.3	157.85	.3	192.47	.3	231.67	.3	275.28	.3	322.40
.4	158.49	.4	193.21	.4	232.50	.4	276.19	.4	323.37
.5	159.14	.5	193.95	.5	233.34	.5	277.11	.5	324.34
.6	159.79	.6	194.69	.6	234.18	.6	278.03	.6	325.31
.7	160.44	.7	195.44	.7	235.02	.7	278.95	.7	326.28
.8	161.09	.8	196.19	.8	235.86	.8	279.87	.8	327.25
.9	161.74	.9	196.94	.9	236.70	.9	280.79	.9	328.22
28.0	162.40	33.0	197.69	38.0	237.54	43.0	281.71	48.0	329.19
.1	163.06	.1	198.45	.1	238.38	.1	282.63	.1	330.16
.2	163.72	.2	199.21	.2	239.23	.2	283.55	.2	331.14
.3	164.38	.3	199.97	.3	240.08	.3	284.48	.3	332.12
.4	165.04	.4	200.73	.4	240.93	.4	285.41	.4	333.10
.5	165.70	.5	201.49	.5	241.78	.5	286.34	.5	334.09
.6	166.37	.6	202.25	.6	242.63	.6	287.27	.6	335.08
.7	167.04	.7	203.01	.7	243.49	.7	288.20	.7	336.07
.8	167.71	.8	203.77	.8	244.35	.8	289.13	.8	337.06
.9	168.38	.9	204.53	.9	245.21	.9	290.07	.9	338.05
29.0	169.06	34.0	205.30	39.0	246.07	44.0	291.01	49.0	339.04
.1	169.74	.1	206.07	.1	246.93	.1	291.95	.1	340.03
.2	170.42	.2	206.84	.2	247.79	.2	292.89	.2	341.02
.3	171.10	.3	207.61	.3	248.65	.3	293.83	.3	342.01
.4	171.78	.4	208.38	.4	249.51	.4	294.77	.4	343.00
.5	172.47	.5	209.16	.5	250.38	.5	295.71	.5	343.99
.6	173.16	.6	209.94	.6	251.25	.6	296.65	.6	344.98
.7	173.85	.7	210.72	.7	252.12	.7	297.59	.7	345.97
.8	174.54	.8	211.51	.8	252.99	.8	298.53	.8	346.96
.9	175.23	.9	212.30	.9	253.86	.9	299.47	.9	347.96
30.0	175.93	35.0	213.09	40.0	254.74	45.0	300.41	50.0	348.96

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TABLE 53.—*Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by weight at 20° C.—Continued*

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
50.0	343.96	55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65
.1	349.96	.1	401.46	.1	455.21	.1	511.34	.1	569.85
.2	350.96	.2	402.52	.2	456.31	.2	512.49	.2	571.05
.3	351.96	.3	403.58	.3	457.41	.3	513.64	.3	572.25
.4	352.96	.4	404.64	.4	458.51	.4	514.79	.4	573.45
.5	353.97	.5	405.70	.5	459.61	.5	515.94	.5	574.65
.6	354.98	.6	406.76	.6	460.71	.6	517.09	.6	575.85
.7	355.99	.7	407.82	.7	461.82	.7	518.24	.7	577.05
.8	357.01	.8	408.88	.8	462.93	.8	519.39	.8	578.25
.9	358.03	.9	409.94	.9	464.04	.9	520.54	.9	579.46
51.0	359.05	56.0	411.00	61.0	465.15	66.0	521.70	71.0	580.67
.1	360.07	.1	412.06	.1	466.26	.1	522.86	.1	581.88
.2	361.09	.2	413.12	.2	467.37	.2	524.02	.2	583.09
.3	362.11	.3	414.18	.3	468.48	.3	525.18	.3	584.30
.4	363.13	.4	415.24	.4	469.59	.4	526.34	.4	585.51
.5	364.15	.5	416.31	.5	470.70	.5	527.50	.5	586.72
.6	365.17	.6	417.38	.6	471.81	.6	528.66	.6	587.93
.7	366.19	.7	418.45	.7	472.92	.7	529.82	.7	589.14
.8	367.22	.8	419.52	.8	474.03	.8	530.98	.8	590.35
.9	368.25	.9	420.59	.9	475.14	.9	532.14	.9	591.56
52.0	369.28	57.0	421.66	62.0	476.25	67.0	533.30	72.0	592.77
.1	370.31	.1	422.73	.1	477.37	.1	534.46	.1	593.99
.2	371.34	.2	423.80	.2	478.49	.2	535.62	.2	595.21
.3	372.37	.3	424.87	.3	479.61	.3	536.79	.3	596.43
.4	373.40	.4	425.94	.4	480.73	.4	537.96	.4	597.65
.5	374.43	.5	427.01	.5	481.85	.5	539.13	.5	598.87
.6	375.46	.6	428.08	.6	482.97	.6	540.30	.6	599.99
.7	376.49	.7	429.15	.7	484.09	.7	541.47	.7	601.31
.8	377.52	.8	430.22	.8	485.21	.8	542.64	.8	602.53
.9	378.55	.9	431.29	.9	486.33	.9	543.81	.9	603.75
53.0	379.58	58.0	432.37	63.0	487.46	68.0	544.98	73.0	604.98
.1	380.61	.1	433.45	.1	488.59	.1	546.15	.1	606.21
.2	381.64	.2	434.53	.2	489.72	.2	547.32	.2	607.44
.3	382.67	.3	435.61	.3	490.85	.3	548.49	.3	608.67
.4	383.70	.4	436.69	.4	491.98	.4	549.66	.4	609.90
.5	384.73	.5	437.77	.5	493.11	.5	550.84	.5	611.13
.6	385.76	.6	438.85	.6	494.24	.6	552.02	.6	612.36
.7	386.80	.7	439.93	.7	495.37	.7	553.20	.7	613.59
.8	387.84	.8	441.02	.8	496.50	.8	554.38	.8	614.82
.9	388.88	.9	442.11	.9	497.64	.9	555.56	.9	616.05
54.0	389.92	59.0	443.20	64.0	498.78	69.0	556.74	74.0	617.29
.1	390.96	.1	444.29	.1	499.92	.1	557.92	.1	618.53
.2	392.01	.2	445.38	.2	501.06	.2	559.10	.2	619.77
.3	393.06	.3	446.47	.3	502.20	.3	560.29	.3	621.01
.4	394.11	.4	447.56	.4	503.34	.4	561.48	.4	622.25
.5	395.16	.5	448.65	.5	504.48	.5	562.67	.5	623.49
.6	396.21	.6	449.74	.6	505.62	.6	563.86	.6	624.73
.7	397.26	.7	450.83	.7	506.76	.7	565.05	.7	625.98
.8	398.31	.8	451.92	.8	507.90	.8	566.25	.8	627.23
.9	399.36	.9	453.01	.9	509.04	.9	567.45	.9	628.48
55.0	400.41	60.0	454.11	65.0	510.19	70.0	568.65	75.0	629.73

TABLE 53.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by weight at 20° C.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	629.73	80.0	663.50	85.0	760.69	90.0	832.76	95.0	911.46
.1	630.98	.1	664.81	.1	762.08	.1	834.26	.1	913.12
.2	632.23	.2	666.12	.2	763.47	.2	835.76	.2	914.78
.3	633.48	.3	667.43	.3	764.86	.3	837.27	.3	916.44
.4	634.73	.4	668.74	.4	766.25	.4	838.78	.4	918.11
.5	635.98	.5	700.06	.5	767.65	.5	840.29	.5	919.79
.6	637.23	.6	701.38	.6	769.05	.6	841.80	.6	921.47
.7	638.48	.7	702.70	.7	770.45	.7	843.32	.7	923.16
.8	639.73	.8	704.02	.8	771.85	.8	844.84	.8	924.85
.9	640.98	.9	705.34	.9	773.25	.9	846.37	.9	926.54
76.0	642.23	81.0	706.66	86.0	774.66	91.0	847.90	96.0	928.24
.1	643.48	.1	707.98	.1	776.07	.1	849.43	.1	929.94
.2	644.73	.2	709.30	.2	777.48	.2	850.96	.2	931.64
.3	645.99	.3	710.62	.3	778.89	.3	852.50	.3	933.35
.4	647.25	.4	711.95	.4	780.30	.4	854.04	.4	935.06
.5	648.51	.5	713.28	.5	781.72	.5	855.58	.5	936.78
.6	649.77	.6	714.61	.6	783.14	.6	857.12	.6	938.50
.7	651.03	.7	715.94	.7	784.56	.7	858.67	.7	940.22
.8	652.29	.8	717.27	.8	785.98	.8	860.22	.8	941.95
.9	653.55	.9	718.60	.9	787.40	.9	861.77	.9	943.68
77.0	654.81	82.0	719.94	87.0	788.83	92.0	863.33	97.0	945.42
.1	656.08	.1	721.28	.1	790.26	.1	864.89	.1	947.17
.2	657.35	.2	722.62	.2	791.70	.2	866.46	.2	948.92
.3	658.62	.3	723.96	.3	793.14	.3	868.03	.3	950.68
.4	659.90	.4	725.30	.4	794.58	.4	869.61	.4	952.44
.5	661.18	.5	726.64	.5	796.02	.5	871.19	.5	954.21
.6	662.46	.6	727.98	.6	797.46	.6	872.77	.6	955.98
.7	663.74	.7	729.32	.7	798.91	.7	874.35	.7	957.76
.8	665.02	.8	730.66	.8	800.36	.8	875.93	.8	959.55
.9	666.30	.9	732.00	.9	801.81	.9	877.52	.9	961.34
78.0	667.58	83.0	733.35	88.0	803.26	93.0	879.11	98.0	963.14
.1	668.86	.1	734.70	.1	804.71	.1	880.70	.1	964.94
.2	670.14	.2	736.05	.2	806.16	.2	882.29	.2	966.75
.3	671.43	.3	737.40	.3	807.61	.3	883.88	.3	968.56
.4	672.72	.4	738.76	.4	809.07	.4	885.48	.4	970.38
.5	674.01	.5	740.12	.5	810.53	.5	887.08	.5	972.20
.6	675.30	.6	741.48	.6	811.99	.6	888.68	.6	974.02
.7	676.59	.7	742.84	.7	813.45	.7	890.29	.7	975.85
.8	677.88	.8	744.20	.8	814.92	.8	891.90	.8	977.58
.9	679.17	.9	745.56	.9	816.39	.9	893.51	.9	979.51
79.0	680.47	84.0	746.92	89.0	817.86	94.0	895.12	99.0	981.35
.1	681.77	.1	748.29	.1	819.34	.1	896.74	.1	983.19
.2	683.07	.2	749.66	.2	820.82	.2	898.36	.2	985.08
.3	684.37	.3	751.03	.3	822.30	.3	899.98	.3	986.88
.4	685.67	.4	752.40	.4	823.79	.4	901.61	.4	988.74
.5	686.97	.5	753.78	.5	825.28	.5	903.24	.5	990.60
.6	688.27	.6	755.16	.6	826.77	.6	904.88	.6	992.47
.7	689.57	.7	756.54	.7	828.26	.7	906.52	.7	994.35
.8	690.88	.8	757.92	.8	829.76	.8	908.16	.8	996.23
.9	692.19	.9	759.30	.9	831.26	.9	909.81	.9	998.11
80.0	693.50	85.0	760.69	90.0	832.76	95.0	911.46	100.0	1,000.00

TABLE 54.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by volume at 60° F.

[Total length of scale 1,000 mm]

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
0.0	0.00	5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90
.1	0.58	.1	28.37	.1	52.76	.1	74.89	.1	95.30
.2	1.16	.2	28.90	.2	53.22	.2	75.31	.2	95.70
.3	1.73	.3	29.43	.3	53.68	.3	75.73	.3	96.10
.4	2.31	.4	29.96	.4	54.14	.4	76.15	.4	96.50
.5	2.89	.5	30.48	.5	54.60	.5	76.57	.5	96.90
.6	3.47	.6	31.00	.6	55.06	.6	76.99	.6	97.30
.7	4.04	.7	31.51	.7	55.52	.7	77.41	.7	97.70
.8	4.62	.8	32.02	.8	55.98	.8	77.83	.8	98.11
.9	5.20	.9	32.53	.9	56.44	.9	78.25	.9	98.51
1.0	5.78	6.0	33.04	11.0	56.90	16.0	78.67	21.0	98.92
.1	6.36	.1	33.55	.1	57.36	.1	79.09	.1	99.33
.2	6.93	.2	34.06	.2	57.82	.2	79.51	.2	99.74
.3	7.50	.3	34.55	.3	58.28	.3	79.93	.3	100.15
.4	8.07	.4	35.06	.4	58.74	.4	80.35	.4	100.56
.5	8.64	.5	35.55	.5	59.20	.5	80.77	.5	100.97
.6	9.21	.6	36.06	.6	59.65	.6	81.19	.6	101.38
.7	9.78	.7	36.55	.7	60.10	.7	81.60	.7	101.79
.8	10.35	.8	37.06	.8	60.55	.8	82.01	.8	102.20
.9	10.92	.9	37.55	.9	61.00	.9	82.42	.9	102.61
2.0	11.49	7.0	38.05	12.0	61.45	17.0	82.83	22.0	103.02
.1	12.05	.1	38.54	.1	61.90	.1	83.24	.1	103.43
.2	12.61	.2	39.03	.2	62.35	.2	83.65	.2	103.84
.3	13.17	.3	39.52	.3	62.79	.3	84.06	.3	104.25
.4	13.73	.4	40.01	.4	63.23	.4	84.47	.4	104.66
.5	14.29	.5	40.50	.5	63.67	.5	84.88	.5	105.08
.6	14.85	.6	40.98	.6	64.11	.6	85.28	.6	105.50
.7	15.41	.7	41.46	.7	64.55	.7	85.69	.7	105.92
.8	15.97	.8	41.94	.8	64.99	.8	86.09	.8	106.34
.9	16.52	.9	42.42	.9	65.43	.9	86.49	.9	106.76
3.0	17.07	8.0	42.89	13.0	65.87	18.0	86.89	23.0	107.18
.1	17.62	.1	43.36	.1	66.31	.1	87.29	.1	107.60
.2	18.17	.2	43.83	.2	66.74	.2	87.69	.2	108.02
.3	18.72	.3	44.30	.3	67.17	.3	88.09	.3	108.44
.4	19.27	.4	44.77	.4	67.60	.4	88.50	.4	108.86
.5	19.82	.5	45.24	.5	68.03	.5	88.90	.5	109.28
.6	20.37	.6	45.72	.6	68.46	.6	89.30	.6	109.70
.7	20.91	.7	46.20	.7	68.89	.7	89.70	.7	110.12
.8	21.45	.8	46.67	.8	69.32	.8	90.10	.8	110.54
.9	21.99	.9	47.14	.9	69.75	.9	90.50	.9	110.96
4.0	22.53	9.0	47.61	14.0	70.18	19.0	90.90	24.0	111.38
.1	23.07	.1	48.08	.1	70.61	.1	91.30	.1	111.81
.2	23.60	.2	48.55	.2	71.04	.2	91.70	.2	112.24
.3	24.13	.3	49.02	.3	71.47	.3	92.10	.3	112.67
.4	24.66	.4	49.49	.4	71.90	.4	92.50	.4	113.10
.5	25.19	.5	49.96	.5	72.33	.5	92.90	.5	113.53
.6	25.72	.6	50.43	.6	72.76	.6	93.30	.6	113.96
.7	26.25	.7	50.90	.7	73.19	.7	93.70	.7	114.39
.8	26.78	.8	51.37	.8	73.62	.8	94.10	.8	114.82
.9	27.31	.9	51.84	.9	74.05	.9	94.50	.9	115.25
5.0	27.84	10.0	52.30	15.0	74.47	20.0	94.90	25.0	115.68

NOTE.—See page 62 for relation to proof spirit.

TABLE 54.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
25.0	115.68	30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59
.1	116.11	.1	138.76	.1	164.92	.1	195.79	.1	231.35
.2	116.54	.2	139.28	.2	165.49	.2	196.46	.2	232.11
.3	116.97	.3	139.71	.3	166.06	.3	197.13	.3	232.87
.4	117.40	.4	140.20	.4	166.63	.4	197.80	.4	233.63
.5	117.83	.5	140.69	.5	167.20	.5	198.47	.5	234.39
.6	118.27	.6	141.18	.6	167.78	.6	199.14	.6	235.16
.7	118.71	.7	141.67	.7	168.36	.7	199.82	.7	235.93
.8	119.15	.8	142.16	.8	168.94	.8	200.50	.8	236.71
.9	119.59	.9	142.65	.9	169.53	.9	201.18	.9	237.49
26.0	120.03	31.0	143.14	36.0	170.12	41.0	201.86	46.0	238.28
.1	120.47	.1	143.63	.1	170.71	.1	202.55	.1	239.06
.2	120.91	.2	144.12	.2	171.30	.2	203.24	.2	239.84
.3	121.35	.3	144.61	.3	171.89	.3	203.93	.3	240.62
.4	121.79	.4	145.10	.4	172.48	.4	204.62	.4	241.40
.5	122.23	.5	145.59	.5	173.08	.5	205.31	.5	242.18
.6	122.67	.6	146.09	.6	173.68	.6	206.00	.6	242.97
.7	123.12	.7	146.60	.7	174.28	.7	206.70	.7	243.76
.8	123.57	.8	147.11	.8	174.88	.8	207.40	.8	244.55
.9	124.02	.9	147.63	.9	175.48	.9	208.10	.9	245.34
27.0	124.47	32.0	148.15	37.0	176.08	42.0	208.80	47.0	246.14
.1	124.92	.1	148.67	.1	176.69	.1	209.50	.1	246.94
.2	125.37	.2	149.19	.2	177.30	.2	210.20	.2	247.74
.3	125.82	.3	149.71	.3	177.91	.3	210.90	.3	248.54
.4	126.27	.4	150.23	.4	178.52	.4	211.60	.4	249.35
.5	126.72	.5	150.75	.5	179.13	.5	212.31	.5	250.16
.6	127.17	.6	151.27	.6	179.75	.6	213.02	.6	250.97
.7	127.62	.7	151.79	.7	180.37	.7	213.73	.7	251.79
.8	128.07	.8	152.31	.8	180.99	.8	214.44	.8	252.61
.9	128.52	.9	152.84	.9	181.62	.9	215.15	.9	253.43
28.0	128.98	33.0	153.37	38.0	182.25	43.0	215.87	48.0	254.25
.1	129.44	.1	153.90	.1	182.88	.1	216.59	.1	255.07
.2	129.90	.2	154.43	.2	183.51	.2	217.31	.2	255.89
.3	130.36	.3	154.96	.3	184.14	.3	218.03	.3	256.71
.4	130.82	.4	155.50	.4	184.77	.4	218.75	.4	257.53
.5	131.28	.5	156.04	.5	185.40	.5	219.48	.5	258.36
.6	131.74	.6	156.58	.6	186.03	.6	220.21	.6	259.19
.7	132.20	.7	157.12	.7	186.67	.7	220.94	.7	260.02
.8	132.66	.8	157.66	.8	187.31	.8	221.67	.8	260.85
.9	133.12	.9	158.21	.9	187.96	.9	222.40	.9	261.69
29.0	133.58	34.0	158.76	39.0	188.59	44.0	223.14	49.0	262.53
.1	134.04	.1	159.31	.1	189.23	.1	223.88	.1	263.37
.2	134.51	.2	159.86	.2	189.88	.2	224.62	.2	264.21
.3	134.98	.3	160.42	.3	190.53	.3	225.36	.3	265.05
.4	135.45	.4	160.98	.4	191.18	.4	226.10	.4	265.89
.5	135.92	.5	161.54	.5	191.83	.5	226.84	.5	266.74
.6	136.39	.6	162.10	.6	192.48	.6	227.59	.6	267.59
.7	136.86	.7	162.66	.7	193.13	.7	228.34	.7	268.44
.8	137.33	.8	163.22	.8	193.79	.8	229.09	.8	269.30
.9	137.80	.9	163.78	.9	194.45	.9	229.84	.9	270.16
30.0	138.27	35.0	164.35	40.0	195.12	45.0	230.59	50.0	271.02

TABLE 54.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
50.0	271.02	55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10
.1	271.88	.1	316.88	.1	366.04	.1	419.50	.1	477.31
.2	272.74	.2	317.82	.2	367.07	.2	420.60	.2	478.52
.3	273.60	.3	318.76	.3	368.10	.3	421.71	.3	479.73
.4	274.47	.4	319.70	.4	369.13	.4	422.82	.4	480.94
.5	275.34	.5	320.65	.5	370.16	.5	423.93	.5	482.15
.6	276.21	.6	321.60	.6	371.20	.6	425.05	.6	483.36
.7	277.08	.7	322.55	.7	372.24	.7	426.17	.7	484.57
.8	277.95	.8	323.50	.8	373.28	.8	427.29	.8	485.78
.9	278.82	.9	324.45	.9	374.32	.9	428.41	.9	487.00
51.0	279.70	56.0	325.40	61.0	375.36	66.0	429.54	71.0	488.22
.1	280.58	.1	326.35	.1	376.40	.1	430.67	.1	489.45
.2	281.46	.2	327.31	.2	377.44	.2	431.80	.2	490.68
.3	282.34	.3	328.27	.3	378.49	.3	432.93	.3	491.91
.4	283.22	.4	329.22	.4	379.54	.4	434.06	.4	493.14
.5	284.10	.5	330.19	.5	380.60	.5	435.19	.5	494.37
.6	284.98	.6	331.15	.6	381.66	.6	436.32	.6	495.60
.7	285.87	.7	332.11	.7	382.72	.7	437.46	.7	496.84
.8	286.76	.8	333.07	.8	383.78	.8	438.60	.8	498.08
.9	287.65	.9	334.03	.9	384.84	.9	439.75	.9	499.32
52.0	288.54	57.0	334.99	62.0	385.91	67.0	440.90	72.0	500.56
.1	289.43	.1	335.95	.1	386.98	.1	442.06	.1	501.80
.2	290.32	.2	336.92	.2	388.05	.2	443.20	.2	503.05
.3	291.21	.3	337.89	.3	389.12	.3	444.35	.3	504.30
.4	292.10	.4	338.87	.4	390.19	.4	445.50	.4	505.56
.5	292.99	.5	339.85	.5	391.26	.5	446.65	.5	506.82
.6	293.89	.6	340.83	.6	392.33	.6	447.80	.6	508.08
.7	294.79	.7	341.81	.7	393.40	.7	448.95	.7	509.34
.8	295.69	.8	342.79	.8	394.47	.8	450.11	.8	510.60
.9	296.59	.9	343.78	.9	395.55	.9	451.26	.9	511.86
53.0	297.50	58.0	344.78	63.0	396.63	68.0	452.42	73.0	513.13
.1	298.41	.1	345.78	.1	397.71	.1	453.58	.1	514.40
.2	299.32	.2	346.78	.2	398.79	.2	454.74	.2	515.67
.3	300.23	.3	347.78	.3	399.87	.3	455.91	.3	516.94
.4	301.14	.4	348.78	.4	400.95	.4	457.08	.4	518.21
.5	302.05	.5	349.78	.5	402.03	.5	458.25	.5	519.48
.6	302.96	.6	350.78	.6	403.11	.6	459.43	.6	520.76
.7	303.87	.7	351.78	.7	404.19	.7	460.61	.7	522.04
.8	304.78	.8	352.78	.8	405.27	.8	461.79	.8	523.32
.9	305.70	.9	353.79	.9	406.36	.9	462.98	.9	524.60
54.0	306.62	59.0	354.80	64.0	407.45	69.0	464.17	74.0	525.89
.1	307.55	.1	355.81	.1	408.54	.1	465.36	.1	527.18
.2	308.48	.2	356.82	.2	409.63	.2	466.55	.2	528.47
.3	309.41	.3	357.84	.3	410.72	.3	467.74	.3	529.76
.4	310.34	.4	358.86	.4	411.81	.4	468.93	.4	531.05
.5	311.27	.5	359.88	.5	412.90	.5	470.12	.5	532.34
.6	312.20	.6	360.90	.6	414.00	.6	471.31	.6	533.63
.7	313.13	.7	361.92	.7	415.10	.7	472.50	.7	534.92
.8	314.06	.8	362.95	.8	416.20	.8	473.70	.8	536.21
.9	315.00	.9	363.98	.9	417.30	.9	474.90	.9	537.51
55.0	315.94	60.0	365.01	65.0	418.40	70.0	476.10	75.0	538.81

TABLE 54.—Master scale for the graduation of hydrometers to indicate percentages of ethyl alcohol by volume at 60° F.—Continued

Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length	Per cent alcohol	Length
	mm		mm		mm		mm		mm
75.0	538.81	80.0	607.33	85.0	682.71	90.0	767.67	95.0	858.24
.1	540.12	.1	608.77	.1	684.81	.1	769.50	.1	860.24
.2	541.43	.2	610.21	.2	686.91	.2	771.33	.2	872.87
.3	542.74	.3	611.65	.3	687.52	.3	773.16	.3	875.15
.4	544.05	.4	613.09	.4	689.13	.4	774.99	.4	877.44
.5	545.37	.5	614.53	.5	690.74	.5	776.83	.5	879.74
.6	546.69	.6	615.97	.6	692.36	.6	778.68	.6	882.05
.7	548.01	.7	617.42	.7	693.98	.7	780.54	.7	884.37
.8	549.33	.8	618.87	.8	695.60	.8	782.41	.8	886.71
.9	550.66	.9	620.33	.9	697.23	.9	784.29	.9	889.06
76.0	552.00	81.0	621.79	86.0	698.86	91.0	786.18	96.0	891.43
.1	553.34	.1	623.26	.1	700.50	.1	788.08	.1	893.82
.2	554.68	.2	624.73	.2	702.14	.2	789.98	.2	896.22
.3	556.02	.3	626.20	.3	703.79	.3	791.88	.3	898.62
.4	557.36	.4	627.67	.4	705.44	.4	793.78	.4	901.03
.5	558.70	.5	629.14	.5	707.10	.5	795.69	.5	903.45
.6	560.05	.6	630.62	.6	708.76	.6	797.62	.6	905.89
.7	561.40	.7	632.10	.7	710.42	.7	799.57	.7	908.34
.8	562.75	.8	633.58	.8	712.08	.8	801.52	.8	910.80
.9	564.10	.9	635.07	.9	713.74	.9	803.49	.9	913.27
77.0	565.45	82.0	636.56	87.0	715.41	92.0	805.46	97.0	915.75
.1	566.81	.1	638.05	.1	717.08	.1	807.44	.1	918.25
.2	568.17	.2	639.54	.2	718.75	.2	809.42	.2	920.77
.3	569.53	.3	641.03	.3	720.43	.3	811.40	.3	923.31
.4	570.89	.4	642.53	.4	722.11	.4	813.39	.4	925.86
.5	572.25	.5	644.03	.5	723.80	.5	815.38	.5	928.46
.6	573.62	.6	645.54	.6	725.50	.6	817.38	.6	931.05
.7	574.99	.7	647.05	.7	727.20	.7	819.40	.7	933.66
.8	576.37	.8	648.57	.8	728.90	.8	821.42	.8	936.28
.9	577.75	.9	650.09	.9	730.60	.9	823.45	.9	938.93
78.0	579.13	83.0	651.61	88.0	732.31	93.0	825.49	98.0	941.61
.1	580.52	.1	653.13	.1	734.02	.1	827.54	.1	944.33
.2	581.92	.2	654.65	.2	735.74	.2	829.60	.2	947.06
.3	583.32	.3	656.18	.3	737.46	.3	831.67	.3	949.80
.4	584.72	.4	657.71	.4	739.19	.4	833.74	.4	952.56
.5	586.12	.5	659.24	.5	740.93	.5	835.82	.5	955.35
.6	587.52	.6	660.77	.6	742.68	.6	837.90	.6	958.16
.7	588.92	.7	662.31	.7	744.43	.7	840.00	.7	961.00
.8	590.32	.8	663.85	.8	746.19	.8	842.12	.8	963.86
.9	591.72	.9	665.40	.9	747.95	.9	844.25	.9	966.74
79.0	593.12	84.0	666.96	89.0	749.72	94.0	846.40	99.0	969.64
.1	594.53	.1	668.52	.1	751.49	.1	848.56	.1	972.56
.2	595.94	.2	670.08	.2	753.27	.2	850.73	.2	975.52
.3	597.35	.3	671.64	.3	755.05	.3	852.90	.3	978.50
.4	598.77	.4	673.21	.4	756.84	.4	855.08	.4	981.50
.5	600.19	.5	674.79	.5	758.64	.5	857.26	.5	984.52
.6	601.61	.6	676.37	.6	760.45	.6	859.46	.6	987.55
.7	603.04	.7	677.95	.7	762.25	.7	861.67	.7	990.61
.8	604.47	.8	679.53	.8	764.06	.8	863.88	.8	993.71
.9	605.90	.9	681.12	.9	765.86	.9	866.10	.9	996.84
80.0	607.33	85.0	682.71	90.0	767.67	95.0	868.34	100.0	1,000.00

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DEPARTMENT OF COMMERCE

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BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 20

ELECTRICAL MEASURING INSTRUMENTS

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ELECTRICAL MEASURING INSTRUMENTS

This Circular supersedes the first edition of Circular No. 20, issued October 1, 1909. Sections 2 to 5, inclusive, in the first edition dealt with regulations, instructions, and fees for electrical tests made by this Bureau. These matters are now the subject of a separate publication, namely, Circular No. 6 of the Bureau of Standards.

S. W. STRATTON,
Director.

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I. INTRODUCTION

The object of this circular is to present briefly the fundamental principles underlying the construction and operation of commercial electrical measuring instruments, together with such information concerning the advantages and limitations of the various types of instruments as will assist the user in the determination of the general type best suited to a given purpose.

The question of sources of error has been treated in some detail, with a threefold purpose: First, to suggest how some errors may be avoided; second, how corrections may be made for known sources of error; and third, to furnish suggestions which will assist those who have to specify instrument performance or to select instruments.

In view of the increasing number of central stations, public-service commissions, and colleges which are equipping testing rooms for the maintenance of electrical standards and the precision checking of electrical instruments, some space has been given to a discussion of the apparatus which seems best suited for use in such laboratories.

While it is not the purpose of this circular to treat in detail the design of electrical instruments, some points of design of more than ordinary interest and importance to the user are briefly discussed.

Electrical measuring instruments may be classified as indicating, integrating, and recording. Indicating instruments either give directly the value of an electrical quantity at the time of observation, or may be so balanced or manipulated as to give such a value. Integrating electrical instruments take account of time, as well as of the electrical quantity. For example, a watthour¹ meter gives a reading proportional to the product of the average power and the time, or, in other words, to the energy that has passed through it. Recording instruments, properly so called, draw a curve or other graphic record showing the variation of an electrical quantity with time.

Electrical instruments may be otherwise classified, according to construction and method of use, into switchboard, portable, and semiportable or laboratory types. They may also be divided into the three following classes, namely, those capable of service on direct current only, those which may be used on direct current and on alternating current, and those which operate on alternating current only.

While the word "instrument" is a general term which may properly include indicating, integrating and recording devices, there is a tendency² to restrict its use to indicating devices and to recording (graphic or curve drawing) devices. Integrating devices are then denoted by the word "meter."

II. INDICATING ELECTRICAL INSTRUMENTS

1. INSTRUMENTS OPERATING ON DIRECT CURRENT ONLY

(a) PRINCIPLE OF OPERATION.—Many types of instruments have been devised for the measurement of direct current and voltage, but the pivoted moving-coil, permanent-magnet, direct-reading instrument has found the widest application. It consists of a light coil free to turn in the field of a fixed permanent magnet. The latter is usually provided with soft-iron pole pieces and a cylindrical iron core in order to give a uniform radial field in which the coil moves. The motion of the coil is opposed by a counter force, usually that of two flat spiral springs which also

¹ The watthour meter has been variously designated by the terms "recording wattmeter," "integrating wattmeter," or "wattmeter." These terms are all open to objection, the last named being especially so. In recent years the use of the term "watthour meter" has been standardized.

² Haraden, *Gen. Elec. Rev.*, 12, p. 474; 1909.

serve to carry the current to and from the coil. Since the deflecting torque is proportional to the product of the (constant) field strength and the current in the coil, and the counter torque of the springs is approximately proportional to the angle through which the coil has turned from the initial position, it follows that the deflection will be approximately proportional to the current strength; that is, the scale will be uniform. The scale may be marked to read the values of current strength corresponding to various deflections. The coil is wound on a thin metal frame, usually of aluminum, and the eddy currents set up in this frame by its motion in the magnetic field tend to bring it to rest. By proper design the motion of the moving system may be made aperiodic (dead beat). It is to be noted that this instrument always measures the strength of current in its moving coil; that is, it acts as an ammeter. To apply it to other measurements, some known relation must exist between the current in the coil and the quantity to be determined.

(b) **DIRECT-CURRENT AMMETERS.**—Since the spiral springs will carry only a small current (a fraction of an ampere), the use of the simple instrument just described is limited to the measurement of relatively small currents. When larger currents are to be measured, use is made of a shunt, that is, a low resistance connected in parallel with the instrument.

Self-contained ammeters have the shunt mounted within the instrument and are used only for moderate currents. For larger currents a separate shunt may be inserted in the circuit with no extra expense for heavy conductors; small conductors then connect the shunt and the instrument. The above statements apply both to switchboard and to portable ammeters. As the latter are usually required to give more accurate results than the former, the use of a separate shunt is, in this case, of further advantage, in that the heat developed in the shunt does not change the temperature of the instrument, and the magnetic field, due to the main current, may be prevented from altering the magnetic field in which the coil moves.

(c) **DIRECT-CURRENT VOLTMETERS.**—Instead of connecting a shunt across the terminals of the instrument, a relatively high resistance may be connected in series with the moving coil, this resistance being adjusted until a certain voltage, say 150 volts, produces the current necessary for full-scale deflection. The instrument thus becomes a voltmeter, and its scale may be marked to read the voltage at its terminals. A multiple-range voltmeter has one or more taps brought out from intermediate points on the series resistance. When voltages higher than the maximum must

be measured, external resistance boxes, called multipliers, are used. Thus, a voltmeter for 0 to 150 volts, whose resistance is 15 000 ohms, will require an additional 15 000 ohms in the multiplier in order to measure up to 300 volts.

(d) **SOME DETAILS OF DESIGN.**—In principle, the ammeter and voltmeter of this type differ only in method of use. In practice, however, some differences of design are necessary. Since a voltmeter should draw as little current as possible from the circuit to which it is connected, the moving coil of the voltmeter is wound with a relatively large number of turns of fine wire, so that the ampere-turns required for full-scale deflection may be had with a small current and the resistance of the voltmeter may be large. The moving-coil ammeter must give full-scale deflection with a relatively small voltage³ at its terminals. This requirement is met by winding the moving coil with relatively coarse wire, or with several wires in parallel, so that the necessary ampere-turns may be had when a relatively low voltage is applied to the coil. To assist in reducing this voltage, it is also customary to use a smaller number of ampere-turns than in voltmeters, thereby decreasing the torque and making it necessary to use springs weaker than those used in voltmeters of similar design.

Since the resistance of a millivoltmeter is low, the resistance of the springs may be appreciable compared with the coil resistance. It is, therefore, usual to make the springs of special alloy having high conductivity. The elastic properties of some of these special alloys are inferior to those of the phosphor bronze commonly used for voltmeter springs. The springs used in millivoltmeters are usually of the minimum strength consistent with good performance as regards frictional errors.

In order to reduce the temperature error of shunted ammeters it is necessary to wind the moving coil to give full-scale deflection with a voltage applied to its terminals, which is only a fraction⁴ of the full-load drop on the shunt.

2. INSTRUMENTS OPERATING ON DIRECT AND ON ALTERNATING CURRENTS

Instruments for use on direct and on alternating currents may be divided into four types, namely, moving-iron, electrodynamometer, electrothermal, and electrostatic.

³ The power lost in an ammeter shunt is equal to EI , where E is the voltage at its terminals and I is the current to be measured. To keep down this loss, as well as the weight, size, and cost of the shunt, E must be kept low.

⁴ For a further discussion of this matter, see p. 31.

(a) **MOVING-IRON INSTRUMENTS, GENERAL.**—Of these four types, the moving-iron ⁵ type has found the widest commercial application. Ammeters of this type may be divided into two main classes: First, movable-core (plunger) instruments, in which an iron core is drawn into a coil when the current flows through the coil; second, those instruments in which a movable iron piece and one or more fixed iron pieces are located within the coil, the usual construction being that in which the movable iron is repelled by the fixed iron. Early instruments of the moving-iron type were constructed with heavy iron cores (sometimes solid rods; in other cases heavy bundles of wires or strips) the length of which was comparable with the length of the solenoid into which they were drawn. The theory of such instruments is now better understood, and it is now known that these instruments were unsuitable for accurate measurements. The quantity of iron should be small, and the length of the path of the magnetic lines in the iron should be small compared with the length of the path in air.

The iron should have low hysteresis, high permeability, and high specific resistance. These qualities are possessed in marked degree by the silicon-steel sheets now used for the best transformers. In addition, the design should be such that the iron is not used near magnetic saturation, as a moving-iron ammeter with nearly saturated core tends to give readings proportional to the average value of an alternating current instead of the effective (square root of mean square) value which is almost always desired.

In the so-called inclined-coil instrument several pieces of sheet iron are carried on a pivoted shaft within the coil. When current flows through the coil, the plates turn so as to be more nearly parallel to the axis of the coil. This is virtually a variation of the movable-core (plunger) instrument just described.

(b) **MOVING-IRON AMMETERS.**—Properly designed and well made moving-iron ammeters, such as are now available, are only slightly affected by large changes of frequency, wave form,⁶ and temperature. On direct current the readings depend slightly on the direction of the current through the

⁵ Often designated by the terms "soft-iron" and "electromagnetic." The latter term is not used in the same sense by all writers; for example, one writer classes permanent-magnet moving-coil and also induction instruments under this head. The term "soft-iron" is also somewhat ambiguous; for example, an induction instrument contains a large amount of soft iron.

⁶ An article by Benischke in the *Elektrotechnische Zeitschrift* (vol. 22, p. 301, 1901) has been frequently quoted as showing that moving-iron ammeters and voltmeters, though practically independent of frequency, are seriously affected by such departures from the sine wave form as are met in practice. While his results were doubtless correct for the old and badly designed instruments he tested, the best modern instruments show only a few tenths of 1 per cent change for as large variations in wave form as would be found in good practice.

coil and upon the value and direction of the current in the preceding readings. The error due to this cause may, in a good instrument, be under 1 per cent of the full-scale reading.

(c) **MOVING-IRON VOLTMETERS.**—These voltmeters have in general a higher time constant (ratio of inductance to resistance) than voltmeters of the same range made on the electro-dynamometer principle. They are thus more affected by change of frequency, but in general this effect is small over the commercial range of frequencies used for lighting and power. In special cases, such as the use on 500 cycles of a moving-iron voltmeter calibrated at 60 cycles, the correction can be calculated if the inductance and resistance of the voltmeter, as well as the frequency, are known. If a well-made moving-iron voltmeter is correct at some definite frequency (say, 60 cycles), the ordinary variations of frequency of commercial circuits will have no appreciable effect on the reading.

(d) **ELECTRODYNAMOMETER INSTRUMENTS, GENERAL.**—This type of instrument is of great importance, especially from the laboratory point of view. The operation of these instruments depends upon the force exerted by one current-carrying circuit upon another, or by a portion of one circuit upon another portion of the same circuit. Instruments of this type usually contain one or more fixed coils within which is arranged a moving coil or system of coils, with provision for passing current through them. If the two sets of coils are connected in series and a current is passed through them, the torque exerted upon the moving system, for a given relative position of the coil systems, is proportional to the square of the current strength and is not dependent upon the direction of the current. When provided with a spring or other suitable counter-force such an apparatus constitutes an ammeter which is equally correct on direct current and on alternating or pulsating current of any frequency⁷ or wave form.

The importance of this type of instrument is due partly to its inherent accuracy on these various kinds of current and partly to its adaptability, as it may be made up as an ammeter, voltmeter, wattmeter, power-factor meter, or phase meter. Several other special applications of the principle are also used.

⁷ This assumes that no change takes place in the distribution of the current over the cross section of the wire. With thick wires and high frequencies the current will be unequally distributed over the cross section, and the reading of the instrument for a given current will vary somewhat with the frequency. It is also assumed that there are no masses of metal near the coils, as the eddy currents induced in such masses would produce magnetic fields, which would combine with the field due to the fixed coils and would thus introduce errors in the indications of the instrument. With fine wire coils used at high frequencies the displacement (capacity) currents between layers also introduce an error.

Since the fundamental electrical standards involve direct current, and a large number of electrical instruments which are used on alternating current can not be tested with direct current, there is a need for "transfer instruments" which can be checked on direct current and which have errors that are negligible, or else small and determinable, on alternating current. The electrodynamicometer type is especially valuable for this purpose, and transfer instruments of this type are used at the Bureau of Standards. The electrostatic type is also used to some extent abroad. In special cases this type has some advantages, but for commercial lighting and power frequencies the electrodynamicometer instrument has the advantage of more rapid and convenient working and of being less affected by vibration.

(e) **ELECTRODYNAMOMETER AMMETERS.**—In an electrodynamicometer ammeter, having the fixed coil and the moving coil in series, and using spiral springs to carry the current into and out of the moving coil, the carrying capacity of the springs limits the current to a small value, usually much less than 1 ampere. In the Siemens electrodynamicometer, the earliest instrument of this type, the current is taken into and out of the moving coil by mercury cups, into which dip the ends of the moving coil. In the Kelvin balance, the axis about which the moving coil turns is horizontal, and ligaments of fine wire are used as supports and conductors. Both of these instruments have done good service in the laboratory, but they are slow and inconvenient to use and require that the current to be measured be quite steady. The readings of Kelvin balances change appreciably due to heating at or near rated load, and the larger sizes have frequency errors which are greater the larger the ampere capacity.

A modification of the Kelvin balance is made in this country by pivoting the moving system and using the counter-torque of a large spiral spring instead of gravity.

By connecting the fixed coil and the pivoted moving coil in parallel the electrodynamicometer ammeter^{*} may be made portable and easy to operate. The moving coil carries only a small fraction of the current. It is essential that the percentage of the current which passes through the moving coil should be constant (within negligible limits) on all the frequencies for which the instrument is to be used and at all working temperatures. This requires that the time constants of the two coils should be

^{*} Such instruments are made by several foreign makers; at this writing, April, 1915, electrodynamicometer ammeters of a new design are being put on the market by an American maker.

equal and their temperature coefficients also equal. Both these objects are attained more or less completely by adding noninductive resistance of low temperature coefficient to each coil, thus reducing both the time constant and the temperature coefficient of each circuit. If these temperature coefficients are made equal, the division of the current between the two coils will depend only upon any temperature difference that may exist between them. A well-made ammeter of this type may be checked on direct current (using the mean of reversed readings) and used as a transfer instrument in the checking of alternating-current ammeters. Such transfer instruments may be much more rapidly operated than Kelvin balances; they are less expensive, and the accuracy of the results will probably be at least equally good.

(f) **ELECTRODYNAMOMETER VOLTMETERS.**—This voltmeter has both its fixed coil and its moving coil wound with moderately fine wire. These coils are connected in series with each other and with a noninductive resistance of low temperature coefficient. This resistance reduces the time constant to a small value, so that well-made instruments of this type, for the usual commercial voltages, may be calibrated on direct current and used on alternating-current circuits with a practically negligible error. Good voltmeters of this type are thus suitable transfer instruments for use in checking working voltmeters.

(g) **ELECTRODYNAMOMETER WATTMETERS.**—The electrodynamic wattmeter is an instrument of great commercial importance. It is used to measure power in alternating-current circuits, and is the most suitable instrument^{*} for testing alternating-current watt-hour meters.

The wattmeter has a fixed coil wound with relatively coarse wire and brought out to two terminals by means of which it may be connected in series with the portion of the circuit in which the power consumption is to be measured. The magnetic field set up by the fixed coil will be proportional to the current strength. The moving coil is of fine wire and has a large noninductive resistance in series with it; this constitutes the voltage circuit, and is connected across the line. The torque exerted upon the moving coil at any instant is proportional to the product of the currents in the two coils, and the instrument measures the power in the circuit. While the power taken by a noninductive load, such as incandescent lamps, may be found even with alternating current by multiplying the current by the voltage, it

^{*} This does not refer to the testing of small alternating-current service meters in position, for which the use of a good portable watt-hour meter (so-called rotating standard) is probably the most convenient method. Portable watt-hour meters, however, should be checked very frequently, and for this purpose the wattmeter is useful.

becomes necessary to use a wattmeter when alternating-current power is to be measured in circuits where the power factor is below unity and is not known.

Before the advent of well-designed and accurate portable wattmeters, use was made of the three-voltmeter method and the three-ammeter method for measuring power. Although still presented in some textbooks, and of some value for teaching principles, these latter methods are not of commercial importance to-day. In some exceptional cases of laboratory work they may prove useful.

(h) **ELECTROTHERMAL INSTRUMENTS, GENERAL.**—Instruments of this type depend upon the heating of a conductor by the passage of a current through it. In most commercial instruments on this principle the expansion of a heated wire is used to operate a pointer.

(i) **HOT-WIRE VOLTMETERS.**—In one of the earliest of hot-wire voltmeters (the Cardew) a fine platinum-silver wire was used, of such a length that it could be connected across a 110-volt circuit without any series resistance. The necessity of accommodating such a length of wire caused the instrument to be bulky; it has now almost disappeared from use. The more modern instruments of the hot-wire type have a working wire 15 or 20 cm (6 or 8 inches) in length. This wire is of small diameter in a voltmeter and has a considerable amount of added resistance in series.

(j) **HOT-WIRE AMMETERS.**—In the hot-wire ammeter the working wire is of larger diameter; in all but low-range unshunted ammeters the wire is electrically divided by silver tap-off strips into several sections which are connected in parallel, to reduce the required drop in the shunt. Above say 5 amperes, shunts are used, except for high-frequency work.

(k) **HIGH-FREQUENCY AMMETERS.**¹⁰—For very high frequencies, such as are used in radiotelegraphy, shunted hot-wire ammeters are by no means reliable, as for such frequencies the effective resistance of the shunt is much greater than for direct (or low-frequency) current, and the time constants of shunt and instrument, which ought to be equal for independence of frequency, may be very different. Ammeters which are free from this objection have been placed on the market in the last few years. In the hot-strip ammeter¹¹ a number of thin alloy strips are arranged in a symmetrical manner so as to avoid change of current distribution with change of frequency. The expansion of one of these strips is used to operate the pointer.

¹⁰ See paper on this subject by Dellinger, *Bulletin of the Bureau of Standards*, 10, p. 91, 1913; *Scientific Paper No. 206*.

¹¹ *Hartmann-Kempf, Elektrotechnische Zs.*, 33, p. 1134, 1911; also *Jahrbuch der drahtlosen Telegraphie*, 6, p. 517; 1912.

(*l*) **HOT-WIRE WATTMETERS.**—A hot-wire wattmeter, made to some extent abroad, is used to measure the power taken by a load, either inductive or noninductive. This wattmeter has two working wires joined in series and connected in parallel with a current shunt which is inserted in one line of the two-wire circuit in which the power is to be measured. The point of junction of the two hot wires is connected through a series resistance to the other line wire. The difference of expansion of the two wires is proportional to the power in the circuit, and actuates the pointer.

In a modification of this hot-wire wattmeter a switch is provided by means of which the connections may be altered so as to give in succession the watts, volts, and amperes of the load.

The hot-wire "wattmeter" used in radiotelegraphy is an unshunted hot-wire ammeter whose scale is not marked in amperes, but in terms of the power absorbed by the instrument itself. A more logical name for this instrument is desirable; the expression "current-square meter" has been suggested.

(*m*) **THERMOCOUPLE AMMETERS.**—Another class of electrothermal instruments depends upon thermal electromotive forces. As an illustration may be mentioned the Duddell thermoammeter, in which the heat produced by the passage of the current through a suitable heating coil acts upon a thermojunction in a loop of wire which constitutes the moving coil of a permanent-magnet direct-current instrument. The use of thermojunctions arranged to be heated by the current to be measured, the thermocurrent operating a galvanometer, is a method which is employed in various forms in laboratory work.

(*n*) **ADVANTAGES AND DEFECTS OF HOT-WIRE INSTRUMENTS.**—The hot-wire instrument is not used in this country to any extent in lighting and power plants. Its defects are relatively large consumption of power, uncertainty of zero, errors due to change of surrounding temperature, and to heating when left in circuit. As the working wire must be run at a fairly high temperature to give proper sensitivity, it is easily damaged by sudden overloads, which would do little or no damage to other forms except the possible bending of a pointer. The good features of the hot-wire instrument, which cause it to be still used for certain classes of work, are its relative independence of frequency, wave form, and stray magnetic fields; the fact that it may be checked with direct current, and that shunts may be used with the ammeter for alternating current of the usual lighting and power

frequencies. For use in the laboratory with unusual frequencies or wave forms, and where facilities are at hand for checking with direct current, the hot-wire instrument has some marked advantages.

(o) USE OF PLATINUM-IRIDIUM IN HOT-WIRE INSTRUMENTS.¹²—A recent improvement in hot-wire instruments consists in the substitution of platinum-iridium alloy for the platinum-silver which had previously been generally used. The actual expansion of a given length of platinum-iridium wire per degree rise of temperature is less than that of a platinum-silver wire of equal length. However, the platinum-iridium wire may be run at a much higher temperature, giving a greater expansion of the wire as used. The platinum-iridium wire is also much stronger, and can be used in finer sizes, thus reducing the current required by voltmeters, and making them much less sluggish in following changes of voltage.

(p) ELECTROSTATIC INSTRUMENTS.—Instruments of the electrostatic type depend upon the attraction of oppositely charged bodies and the repulsion of similarly charged ones. As these forces are relatively small, such instruments can not well be made as ammeters, and in fact it is difficult to construct satisfactory voltmeters on this principle for the ordinary 110-volt range. The great advantage of this type of voltmeter is that it takes no current, when used on direct-current circuits, and an extremely small current when used on alternating-current circuits. It is not affected by frequency changes, wave form, or stray magnetic field. It has the defect of small ratio of torque to weight of moving parts, so that frictional errors are hard to avoid. For this reason, low-range instruments of this type are usually made with a suspension strip or wire in place of pivot and jewel bearings.

While these instruments are used abroad to some extent, in this country they find little use except in the laboratory. The electrostatic ground detector operates on the same general principle as the electrostatic voltmeter. Wattmeters may be constructed on the electrostatic principle,¹³ but they are too delicate for any but laboratory use. Such wattmeters are of value in some special applications; for example, in determining the power losses in insulating materials under electrical stress.

¹² Hartmann-Kempf, *Elektrotechnische Zs.*, **81**, p. 269; 1910.

¹³ Electrostatic Method for the Measurement of Power, by Patterson, Rayner, and Kinnes, *J. Inst. Elec. Eng.*, **51**, p. 294; 1913.

3. INSTRUMENTS OPERATING ON ALTERNATING CURRENT ONLY.

(a) **INDUCTION INSTRUMENTS.**—These instruments have a fixed core of laminated iron wound with one or more coils of wire, and a moving element, usually a metal disk or cup, which is pivoted to move in the air gap of the iron core. They are called induction instruments because they depend upon the interaction of the induced currents in the cup or disk with the inducing field.

The general principle of induction instruments may be understood by considering the induction wattmeter or the induction watthour meter. An iron core is wound with a large number of turns of fine wire, and to this winding the voltage of the circuit is applied. The metal disk or cup forming the moving element passes through an air gap in the core. Eddy currents are set up in the moving element by the flux from this voltage coil. The load current passes through a coarse winding on another arm of the iron core or on a separate core. The eddy currents produced in the disk by the voltage flux react with the magnetic field of the current coil producing a torque which tends to drive the disk continuously in one direction.

In an induction indicating instrument this rotation may be opposed by gravity or by a spiral spring. The latter is usually employed, as it permits a rotation of about 300° , thus giving a great length of scale for a given diameter of the instrument.

In an early form of induction ammeter the fixed laminated electro-magnet is wound with a single coil. A single turn of copper strip, called a "shading coil," surrounds about half of the polar projection of the iron core. The induced currents in this strip retard the phase of the magnetic flux in the part of the core inclosed by the strip, and the resultant flux in the core as a whole shifts across the pole face. This shifting flux induces currents in the disk, or cup, and the action between the shifting magnetic field and the induced currents tends to set the cup or disk in rotation.

A simple induction ammeter made as just outlined would be very unsatisfactory, as its readings would vary greatly with change of frequency and of temperature. Variation with frequency may be compensated for to some extent by connecting a noninductive resistance in parallel with the magnetizing coil. As the frequency increases, a larger proportion of the current will flow through the noninductive resistance, thus preventing the increase of reading which would otherwise result. By making the non-

inductive resistance of copper, a certain amount of compensation for temperature is secured. An increase of temperature increases the resistance of the noninductive branch, thus causing more current to flow through the magnetizing coil, and tending to offset the effect of the increased resistance of the moving element, which acts to decrease the torque.

Induction instruments of the rotary-field class are similar to induction motors, except that the moving element contains no magnetic material. The moving element is usually in the form of a cup, and an iron core is ordinarily supported within the cup. The laminated iron stator contains two sets of windings, the currents in them differing in phase. This phase difference may be produced in the ammeter by making the time constants of the two circuits different, as by adding noninductive resistance to one circuit; the circuits are then connected in parallel. In the "series-transformer" induction ammeter,¹⁴ which is probably the most advanced form of induction ammeter, the current to be measured flows through a single circuit wound on the two cores of a laminated electromagnet. This winding corresponds to the primary winding of a current transformer. A secondary winding under the main winding has a current induced in it which will be approximately proportional to the main current, over a considerable range of frequency and temperature. The electromagnet has polar extensions between which a metal cup is pivoted to turn, and these polar projections are wound with coils through which the secondary current is passed. The phase relations of the primary and secondary currents and the location of the magnetizing coils included in the secondary circuit are such as to give a rotary field in the air gap, thus exerting a torque on the moving element, as in an induction motor. As the temperature increases, the torque would decrease (if the flux remained constant), due to the increase of resistance of the moving element. However, as the secondary winding is of copper, its resistance will also increase, thus causing the flux to increase in the same proportion and maintaining the torque unchanged.

The induction voltmeter is essentially a low-range induction ammeter with a suitable noninductive resistance in series, and with a scale marked to read the voltage at the terminals.

The advantages claimed for the induction instrument for switchboard work where the frequency and wave form do not vary greatly are as fol-

¹⁴ MacGahan, *Electric J.*, 4, p. 113, 1907; *Proc. Am. Inst. Elec. Eng.*, 31, p. 1203, 1912.

lows: Simplicity and ruggedness of the moving element, high ratio of torque to weight of moving element, relative independence of stray magnetic fields, and great length of scale for a given area occupied by the instrument. If properly designed to reduce the frequency errors to a negligible value, the induction ammeter is suitable for portable work for the reasons just given. The induction ammeter may be adjusted to read correctly on two frequencies, such as 25 and 60 cycles. The error at frequencies between these values is stated to be less than 1 per cent. The induction wattmeter is limited to a single frequency. The induction voltmeter may be arranged for use on two frequencies, a switch (or its equivalent) being used to alter the impedance of the voltmeter so as to make it read correctly on the frequency in use.

III. INTEGRATING ELECTRICAL INSTRUMENTS (METERS)

1. AMPEREHOUR METERS

Amperehour meters measure the product of the average current in amperes by the time in hours. They are of two general types: First, those depending on electrolysis; second, those of the motor type. The Edison chemical meter, which has gone out of use, contained plates of zinc in a solution of zinc sulphate. A small fraction of the current to be measured passed through this cell and transferred zinc from one plate to another. The loss of weight gave a measure of the amperehours which had passed through the meter. Another chemical meter which is used to some extent depends on the decomposition of water by the passage of the current. A third form, which was developed in England, depends on the electrolysis of a solution containing a salt of mercury. The passage of a current transfers mercury electrolytically from a mercury anode to an iridium cathode, from which the mercury falls into a tube. The height of the column of mercury is shown by a graduated scale alongside the tube. The scale is usually marked in kilowatthours on the assumption of a stated supply voltage.

Amperehour meters of the motor type may be classified as commutator meters and mercury motor meters. Commutator amperehour meters have an armature free from iron arranged to rotate between the poles of a strong permanent magnet. The winding of the armature is such that the meter develops full speed with about 1 to 2 volts at the brushes and with a small armature current. The armature is connected to the terminals of a shunt which carries the greater part of the current to be measured.

Mercury amperehour meters have a chamber within which a copper disk (or, in some designs, a cup) is submerged in mercury and arranged to rotate. The current enters the mercury at one side of the chamber and flows through the disk. A permanent magnet produces a magnetic field through the disk, and the disk is caused to rotate by the interaction of the current in the disk with the magnetic field. Like the other forms just described, this amperehour meter operates only on direct current.

The principal application of the amperehour meter as such is in connection with storage batteries. By arranging the connections to the meter shunt so that the speed of the meter on discharge exceeds the speed on charge (for a given current) by a definite percentage depending on the amperehour efficiency of the battery, the meter will aid in determining the state of charge of the battery.

Abroad, the amperehour meter is largely used as a substitute for the watthour meter in the sale of electric current, especially in England.¹⁵ It is customary to mark the dials to read kilowatthours at some stated voltage. The chief advantages of the amperehour meter for this purpose are its lower first cost and the absence of voltage (potential) circuits which consume energy continually and are liable to burn out or develop open circuits.

2. DIRECT-CURRENT WATTHOUR METERS, THOMSON TYPE

Integrating meters as now used in this country are practically all of the motor type and are watthour meters; that is, they measure electrical energy. They may be classified as direct-current meters and alternating-current meters. The Thomson watthour meter (the so-called "recording watt-meter") is the earliest example of American direct-current motor meter, and most other direct-current watthour meters differ from it only in details of design and construction. This meter contains a small commutator motor free from iron. The line current passes through the fixed field windings, and the armature, which is wound with fine wire, is connected through a series resistance across the line. On the shaft of the motor is a disk of copper or aluminum which rotates between the poles of several permanent magnets. The upper end of the armature shaft has a worm which engages with the first gear wheel of the register. The best meters of this general type, as now made, have much lighter moving elements, higher

¹⁵ For a description of the principal foreign amperehour meters, see *Electrical Instruments and Meters in Europe*, by H. B. Brooks, issued by the Bureau of Foreign and Domestic Commerce, Washington, D. C.

torque, and smaller losses in the voltage circuit than the original Thomson meter. It is important that the loss in the voltage circuit be small, as the total loss in a large installation is appreciable and is going on as long as the voltage is on the lines. Heating due to losses in the meter is also objectionable because it tends to affect the accuracy of the meter.

3. DIRECT-CURRENT WATTHOUR METERS, MERCURY TYPE

The driving element of this type of meter consists of a copper disk submerged in mercury. The line current enters the mercury chamber, flows diametrically across the disk and out at the other side. A laminated electro-magnet, wound with fine wire and connected across the line, provides a magnetic field which passes up through the copper disk and down through it on the other side of the axis of rotation. A ring of laminated iron above the disk is used to reduce the reluctance of the magnetic circuit. The interaction of the current in the disk with the magnetic field causes the disk to rotate. The upper end of the shaft carries an aluminum disk which rotates between the poles of drag magnets and provides the retarding torque.

A three-wire mercury motor meter has recently been developed. It consists of two motor elements, one above the other, with a common shaft. Special arrangements are provided to prevent the escape of mercury from the upper element.

The mercury motor meter has several advantages. It dispenses with the commutator, which is one of the most troublesome features of the usual direct-current meter. It has a very low drop of potential in the current circuit, which adapts it for use with shunts. It is only slightly affected by stray magnetic fields. The weight of the moving element is carried by flotation. It has the disadvantages of small torque and of being limited to ranges of 10 amperes and above.

4. ALTERNATING-CURRENT WATTHOUR METERS

(a) USE OF COMMUTATOR METERS ON ALTERNATING-CURRENT CIRCUITS.—The Thomson watthour meter and other meters designed on the same principle for direct-current service may be used on alternating-current circuits with an error which is occasioned partly by the inductance of the armature circuit and partly by eddy currents. This error is smaller, the lower the frequency and the nearer the power factor of the load is to unity. To avoid this error such meters have sometimes been "lagged" by connecting a noninductive resistance in parallel with the current coil of the meter.

(b) **INDUCTION WATTHOUR METERS.**—There is little occasion, however, for the use of commutator meters on alternating currents, as the induction watthour meter is much to be preferred, having no moving wire, no contacts, a much lighter moving system, better ratio of torque to weight, and better performance. The losses in the induction meter are much smaller, and in most designs the effect of stray magnetic fields is much smaller than in the direct-current meter.

The induction watthour meter depends on the same general principle as the induction wattmeter, as briefly described on page 16. The moving element is extremely simple, consisting usually of an aluminum disk mounted on a vertical spindle; the spindle is supported by a jewel bearing, and has a worm which engages with a worm wheel on the register. The disk serves a double purpose—the driving torque is due to the interaction of currents induced in the disk with the magnetic fields inducing them, and the retarding torque is due to eddy currents set up in the disk by one or more permanent magnets between whose jaws the disk revolves. The induction watthour meter must be adjusted to operate at some one definite frequency.

(c) **EFFECT OF WAVE FORM.**—Induction meters are affected to some extent by variations in the wave form in the circuits on which they are used. This was of consequence in the earlier years of alternating-current distribution, when generators were designed for maximum weight efficiency (or other desiderata) with more or less complete ignorance or disregard of the wave form. The present tendency is to design generators to give a reasonably good approximation to a sine wave.

5. PORTABLE WATTHOUR METERS

In order to facilitate the testing of electric meters on the premises of consumers, portable watthour meters have been devised. These are sometimes called "rotating standards"; they are substantially the same in construction as the service meters, but usually have arrangements for varying the current range by having a separate coil for each range, or a stranded coil whose sections may be grouped in various ways, or by a combination of these methods. The style of mounting is such as to adapt them for portable use, and the dials are such as to enable a close reading to be made for very short runs. These meters are constructed on the induction principle for alternating current. This gives a satisfactory instrument for commercial work on a definite frequency. Direct-current meters, on account of the use of commutator and brushes and the much higher drop in the field

coils, are not so satisfactory as the former. In either case the portable watthour meter should be considered as a secondary instrument, liable to change in use, and it should be frequently checked by reliable standard instruments.

The annual reports of the Committee on Meters of the National Electric Light Association contain much valuable information on watthour meters. The Electrical Meterman's Handbook, prepared by this committee,¹⁸ contains a large amount of information on American watthour meters as well as the auxiliary apparatus required for testing meters.

IV. RECORDING ELECTRICAL INSTRUMENTS

1. GENERAL DISCUSSION

Recording (also called graphic or curve-drawing) electrical instruments make a graphic record of the varying values of current, voltage, power, or other electrical quantities in the circuit to which they are connected. Almost any of the types of indicating instruments previously referred to may be utilized in the design of a recording instrument, but in general the permanent-magnet moving-coil type is used for direct-current work, and the moving-iron, electro-dynamometer, and induction types for alternating-current work. Recording instruments are useful for giving a check on the operation of plants, for determining the power required by motor-driven machinery, determining voltage regulation, and similar purposes. They may be broadly classified as direct-acting and as relay instruments.

2. DIRECT-ACTING RECORDING INSTRUMENTS

A direct-acting recording instrument is essentially an indicating instrument having a pen, pencil, or stylus attached to its pointer to draw a record on a paper chart which is moved under the pointer by clockwork or its equivalent. The friction of the marking device would interfere seriously with the motion of the pointer of an ordinary indicating instrument, and the design of a recording instrument must take this into account. This is usually done by modifying the operating system so as to get a large value of torque. In some recording instruments a large torque is made unnecessary by allowing the moving system to swing freely except at certain regular intervals when a bar is depressed, forcing a stylus against the paper and making a dot. By arranging the apparatus so as to make these dots fre-

¹⁸ Published by the National Electric Light Association, 33 West Thirty-ninth Street, New York, N. Y.

quently, an approximation to a continuous curve is made. This form of instrument may also be regarded as a relay instrument, since a force other than that due to the operating system assists in making the record. Another method which is used for avoiding friction consists in causing the discharge from a spark coil to jump from the end of the pointer through the paper to the drum on which the paper is carried, thus piercing the paper.

3. RECORDING INSTRUMENTS ON THE RELAY PRINCIPLE

In a recording instrument on the relay principle the operating system is relieved of the work of making the record directly, and merely operates relay contacts which bring into action auxiliary devices, such as solenoids, which operate the pen. One of the chief advantages of this type is that the operating system (measuring system) of the instrument has very little work to do, and hence may be designed to take a relatively small amount of power as compared with a direct-acting recording instrument of the same type. This feature is sometimes important when the recording instrument must be operated from instrument transformers whose output is limited, or which already have other instruments connected, and have but little margin of output available for operating the recording instrument. Another advantage of the relay type instrument is that a slight displacement of the pen from the true reading results in full torque being applied to restore the true reading, whereas in the direct-acting type the restoring torque is only proportional to the amount of the displacement. The relay type is necessarily more complicated and more expensive than direct-acting instruments.

In a recent recording instrument, which may be classed as a relay instrument, there are no electrical relay contacts, but the position of a galvanometer pointer mechanically relays the work of making the record to a small auxiliary motor running at constant speed. This motor also moves the paper.

V. INSTRUMENT TRANSFORMERS

1. GENERAL DISCUSSION

Instrument transformers are of two classes, current transformers and voltage transformers. Current transformers are used to reduce large alternating currents to smaller values which can be measured conveniently, and similarly, voltage transformers reduce high voltages to values which can be measured on an ordinary voltmeter. Their use makes it possible to

exclude high voltages from the instruments, thus insuring greater safety to the operator; the instruments can be wound with standard current and voltage windings, usually for 5 amperes, 110 volts, and the instruments may be placed in any convenient location, connection to the transformers being made with small wires.

2. VOLTAGE TRANSFORMERS

A voltage transformer ¹⁷ is essentially a lighting or power transformer of small capacity used to step down the line voltage for the operation of instruments. The rated output of the transformer is generally made considerably less than the output which could be safely carried without overheating; this limitation of the output is for the purpose of limiting the variation of the ratio of transformation ¹⁸ with change of output. To minimize the error in the ratio, voltage transformers may be wound so that the ratio is correct for an average secondary load; it will then be slightly low at no load and slightly high at rated load. The error is thus zero at the average load, and the maximum error in the ratio is less than if the winding had been designed to give correct ratio at either no load or full load.

(a) PHASE ANGLE OF VOLTAGE TRANSFORMERS.—In an ideal voltage transformer, having no losses, the secondary induced electromotive force would be exactly in opposition to the primary voltage. In an actual transformer, however, the iron and copper losses and magnetic leakage cause the no-load secondary voltage to lead opposition to the primary applied voltage by a small angle. This small angle is called the "phase angle" of the transformer; it amounts to only a small fraction of a degree in good transformers, and its effect is negligible, for most practical purposes, if the secondary current is small. The effect of adding a noninductive load to the secondary is to decrease this angle of lead; as the load is increased, the secondary terminal voltage usually passes through the position of opposition to the primary and lags behind opposition.

¹⁷ The term "potential transformer" has been in use since the beginning of the alternating-current art. However, as the word "potential" when used in this sense is incorrect unless assumed to be a contraction of "potential-difference," and is used in other senses in scientific work, it has been suggested that the expression "voltage transformer" be used instead, as it is not ambiguous. The term "pressure transformer" is an objectionable one, as are also the words "pressure" and "tension" when used in the sense of electromotive force or difference of potential.

¹⁸ The ratio of transformation of a voltage transformer is the quotient of the voltage applied to the primary terminals divided by the voltage available at the secondary terminals. The ratio of transformation is a variable quantity, and while it is nearly equal to the quotient of primary turns divided by secondary turns (in properly designed voltage transformers) it should be distinguished from the ratio of turns.

Voltage transformers usually operate on circuits of approximately constant voltage and frequency, and their design and construction present no special problems not found in lighting and power transformers for the same voltages.

3. CURRENT TRANSFORMERS

(a) GENERAL DISCUSSION.—Alternating-current ammeters are not well adapted for operation from shunts, as a rule, and the windings of shunted instruments are necessarily at the same potential as the shunts. For these reasons, and others of perhaps less importance, the current transformer ¹⁹ is widely used.

While the current transformer does not differ in principle from ordinary lighting or power transformers, it is rather sharply limited as to design if good results are to be secured. The magnetic induction must be kept low, the core must be of good material (such as silicon steel), and the magnetic circuit should be short and have interlaced joints, if joints are present. The number of ampere-turns of each winding should not be less than 300, as a rule. This value ²⁰ refers to the rated maximum current.

(b) RATIO OF TRANSFORMATION.—The ratio of transformation of a current transformer is the quotient of the primary current divided by the secondary current; this ratio, in a good transformer which is not overloaded, is nearly equal to the quotient of the number of secondary turns divided by the number of primary turns. The ratio of transformation depends on the secondary current, and in nearly all cases the ratio becomes greater as the secondary current decreases. The ratio is also dependent on the impedance of the secondary circuit, including the secondary winding itself, the secondary instruments, and the connecting wires. In general, an increase in the impedance of the apparatus connected to the secondary will increase the values of the ratio for all values of secondary current and also increase the rate of change of the ratio with changing secondary current. The impedance of the secondary circuit should therefore be reduced to the minimum.

¹⁹ All transformers which have closed secondary circuits transform both the voltage and the current. The terms "current transformer" and "voltage transformer" refer merely to the use to which the transformers are put. In the voltage transformer the thing of importance is the voltage; the primary voltage may be very great while the currents are small. In the current transformer the reverse is true; the voltages are small and are not recorded or used while the currents are important and the primary current may be very large. The current transformer is sometimes called a "series transformer."

²⁰ This figure is given by Edgcumbe, *Industrial Electrical Measuring Instruments*, p. 140. It is too small for any but special cases, such as the operation of one ammeter. For the better types of current transformer used with wattmeters or watt-hour meters, the number of ampere-turns should be not less than 800 to 1,000, as a rule.

(c) **PHASE ANGLE OF CURRENT TRANSFORMER.**—In an ideal current transformer whose core had infinite permeability and no core loss, and in which there was no leakage flux, the secondary current would be exactly in opposition to the primary current and the ratio of transformation would equal the ratio of turns. The effect of the magnetizing current and the core loss is to cause the secondary current to be slightly in advance²¹ of opposition to the primary current. The amount of this advance is called the "phase angle"; it is dependent on the resistance and reactance of the secondary circuit, and usually decreases as the secondary current increases. If the secondary circuit is noninductive, the magnetizing current produces the phase angle, and the core loss causes the ratio of transformation to depart from the ratio of the number of turns. This statement is correct to within small quantities of the second order. With a secondary circuit having reactance but no resistance, the magnetizing current would affect the ratio and the core loss would produce the phase angle. For such secondary loads as are usually found in practice the magnetizing current and the core loss each affect both ratio and phase angle.

The phase angle of a current transformer is of no consequence when the secondary circuit contains only ammeters or other apparatus, such as trip coils, which depend only on the current strength. If wattmeters, watthour meters, or power factor meters are to be operated, it is important to have the phase angle small. This might be accomplished by having a sufficiently large reactance in the secondary circuit, but this would have the undesirable effect of causing the ratio of transformation to increase considerably as the secondary current decreased. It is therefore better, in general, to keep the secondary resistance and reactance low, thus obtaining a good ratio performance, and to keep the phase angle as small as possible by good design and good materials in the transformer. In measuring single-phase power or energy accurately with a wattmeter or a watthour meter in connection with current or voltage transformers, the observed value must be corrected for the instrument error, then multiplied by the ratio of the voltage transformer and by the ratio of the current transformer. These ratios must be known for each transformer as a result of tests, and are most conveniently taken from curves showing values of ratio for various secondary conditions. If the load to be measured has nearly unity power factor, phase angles may be neglected unless in extreme cases of current transformers whose design

²¹ This applies to the case of secondary connected loads having moderate reactance. When the secondary connected load has a large reactance, as in the case of oil-switch trip coils and relay coils, the secondary current may lag behind opposition to the primary current, at least for some values of the secondary current.

entirely unfits them for power or energy measurements. As an extreme case may be mentioned a current transformer tested by this Bureau. The transformer was of the "hole type," having an opening to enable it to be slid over a bus bar carrying 100 amperes maximum. The ampere turns at full load were thus very low, being only 100 as against the minimum of 300 referred to on page 25. The phase angle was excessive, ranging from 18° at 0.5 ampere secondary current to 5° at 5 amperes. The ratio varied 7 per cent over the same range of secondary current. This transformer was intended by the maker for the operation of a relay only, in which case the phase angle is not objectionable. If the power factor of the load is appreciably below unity, it is necessary to take into account not only the ratios but also the phase angles of the instrument transformers. A discussion of this matter, with illustrative examples and tables, is given by L. T. Robinson in *Transactions of the American Institute of Electrical Engineers*, volume 28, page 1005, 1909. This article also discusses the matter of phase angle corrections to measurements in polyphase circuits with the help of current and voltage transformers.²²

(d) SECONDARY CIRCUIT TO BE KEPT CLOSED.—The secondary circuit of a current transformer should never be opened while current is flowing through the primary, not only on account of the rise of voltage at the secondary terminals, which may become dangerously high, but also because both the ratio and the phase angle will be changed. With current flowing in the primary and the secondary circuit open, the magnetic flux in the core rises to an abnormally high value, and the heating due to the greatly increased iron loss may damage the insulation. The magnetic condition of the core is also altered, so that on a return to normal condition of the secondary circuit the magnetizing current and the core loss are greater than normal, thus changing the ratio and the phase angle.²³ The same abnormal condition of the core will occur if a direct current of sufficient strength flows through either of the windings.

(e) EFFECT OF DIRECT-CURRENT FLOW.—A case was reported to the Bureau in which the accuracy of a current transformer used in connection with an important watthour meter was appreciably affected by the flow of direct current through the secondary winding. The secondary circuit was connected at two places to two independent station grounds. One of these grounds became defective, and direct current which normally

²² See also N. E. L. A. Meter Code, 1912, p. 125; *Meterman's Handbook*, p. 296; *American Handbook for Electrical Engineers*, p. 1819.

²³ Agnew and Fitch, *Bulletin of the Bureau of Standards*, 6, p. 297, 1910; *Scientific Paper No. 130*.

would have flowed to earth through this ground passed along the secondary wiring, through the secondary coil of the transformer, and to earth by way of the second ground.

In case the secondary circuit is accidentally opened, or if the core becomes magnetized by the flow of direct current through either winding, the core may be brought back to its normal condition (demagnetized) by passing at least half the rated primary current through the primary winding with a resistance of 10 ohms or more connected to the secondary, in series with the secondary instruments. This resistance should then be gradually reduced to zero by steps of 1 ohm or less.

The phase angle of an instrument transformer depends on the frequency, the secondary current, and the secondary impedance.

VI. PERFORMANCE OF ELECTRICAL INSTRUMENTS

1. ACCURACY, SENSITIVITY, AND RELIABILITY

The distinction between accuracy and sensitivity should be carefully noted. For example, a particular indicating instrument may be sensitive, so that a change in the quantity under measurement of, say, 0.1 per cent will give a perceptible change in the position of the pointer. However, there may be defects in the design or construction of the instrument such that an error of 1 per cent may enter into the result without the possibility of detection except by the simultaneous use of a second instrument which is able to give results correct to, say, 0.1 per cent under the given conditions. The first instrument is *sensitive* to 0.1 per cent, but *accurate* to only 1 per cent. Consider a third instrument which is sensitive to 0.2 per cent but is accurate under the given conditions of use to 0.5 per cent. It thus has double the accuracy of the first instrument though only half as sensitive, and for most purposes it would be preferable to the first instrument.

The reliability of an electrical instrument is an important property which is difficult to determine except through extended experience. It is to be distinguished from permanency, though the two are closely related. To secure reliability requires that the operating principle be a suitable one for the purpose, the design such as tends to rigidity, strength, and permanence of adjustments; that the materials used be suitable, and that no materials be employed which may occasion damage²⁴ to any part; and,

²⁴ The use of soft rubber tubing, for example, is liable to cause corrosion of springs and connecting wires. Similar results have been occasioned by hard rubber. Superior substitutes for these materials are now available and are coming into extensive use.

further, that the materials be properly worked and assembled. For example, even the best magnet steel will give poor results if the heat treatment is not suitable. These conditions show upon what complex conditions the reliability of electrical instruments depends, and hence to what a large extent the experience, facilities, and shop system of the maker affect the reliability of the product.

The accuracy, sensitivity, and reliability of electrical instruments are determined by their design and the materials and care used in their construction. No instruments made are "absolutely accurate" or entirely independent of their surroundings, and a knowledge of the magnitude of the errors likely to occur, the origin of these errors, and the means used to make the errors negligible or as small as possible, is of value in enabling one to choose between different types of instruments which may be used for a given work, and in obtaining the best results from an instrument under working conditions.

2. EFFECTS OF CHANGE OF ROOM TEMPERATURE

(a) GENERAL DISCUSSION.—A change of temperature of 1°C produces various effects on the parts of an instrument. These effects differ widely in magnitude. For example, the linear expansion of the metal parts will be of the order of 10 to 20 parts in a million, and the change of resistance of manganin and some other alloys will be of the same order. Both the foregoing may be neglected in all ordinary cases. The change of the elastic force of a spring will be several parts in ten thousand, and the change of resistance of a copper coil will be about 4 parts in a thousand.

(b) TEMPERATURE COEFFICIENTS OF DIRECT-CURRENT VOLTMETERS.—The effect of an increase of temperature of 1°C is to weaken a phosphor-bronze spring about 0.04 per cent, and hence if no other part of an instrument was affected by the temperature change, the reading of the instrument would be increased by this percentage. In an instrument of the permanent-magnet moving-coil type, the strength of the magnetic field in the air gap will usually decrease by about 0.02 per cent²⁵ for a rise of temperature of 1°C . This decrease in the field strength tends to reduce the reading of the instrument, and hence the reading will in general be increased by only 0.02 per cent by a rise of room temperature of 1°C . This figure applies to a permanent-magnet moving-coil instrument used as a milliammeter with

²⁵ This is an average of the values found by Sanford and Fearing for the magnetic fields of six instruments from three makers. The individual values ranged from -0.01 to -0.03 per cent.

the whole current to be measured flowing through the moving coil. If the instrument is to be used, in connection with some added resistance, as a voltmeter, the effect of temperature change on the resistance of the instrument circuit must also be considered. It is evident that if the resistance of the voltmeter can be made to increase by about 0.02 per cent²⁶ per degree C, the current taken by the voltmeter (when a definite voltage is applied to its circuit) will decrease 0.02 per cent for a rise of 1° C, thus offsetting the resultant temperature coefficient of the magnet and springs, and making the instrument compensated for room temperature changes. For example, the moving coil may have 60 ohms resistance, and be of copper wire whose temperature coefficient is approximately 0.4 per cent per degree C. If to this coil be added a series resistance of manganin, constantan, or other suitable alloy of negligible temperature coefficient, so as to make a total of 1200 ohms, the resistance of the instrument will increase 0.02 per cent per degree C rise of temperature, and the voltmeter will be compensated for ordinary changes of room temperature.

(c) TEMPERATURE COEFFICIENTS OF DIRECT-CURRENT AMMETERS.—On account of the necessity, for commercial reasons, of keeping down the size, weight, and cost of switchboard ammeter shunts, as well as the power lost in them, shunted ammeters are designed to give full-scale deflection for very low voltages, usually from 50 to 75 millivolts. As the shunts are usually made of resistance alloy of low temperature coefficient, while a considerable part of the instrument circuit consists of copper, the proportion of the total current which passes through the instrument will change appreciably with changing room temperature. The resulting temperature errors range from less than one-tenth per cent to about four-tenths per cent per degree C, so that in extreme cases errors of 5 per cent or more may be caused by room temperature changes. This is ordinarily not a matter of importance, as switchboard ammeters serve mainly as indicators to guide in the operation of a plant, to prevent overloading of generators, motors, or feeders. Such ammeters, however, should not be used where accuracy is required,²⁷ as, for example, in making efficiency tests or in checking watt-hour meters, unless suitable correction is made for the effect of room temperature. It is, however, preferable to use instruments having smaller corrections, as it is

²⁶ This is an average value, and to compute the percentage of manganin (or similar alloy) for accurate temperature compensation for a given instrument would require the determination of its temperature coefficient as a milliammeter.

²⁷ F. P. Cox, *Transactions American Institute of Electrical Engineers*, 24, p. 181, and E. B. Rosa, *discussion*, p. 223; 1905.

not always possible to determine temperatures accurately at the points where they need to be known.

(d) **TEMPERATURE COMPENSATION OF DIRECT-CURRENT AMMETERS.**—Portable shunted ammeters for direct current should be compensated for temperature. The simplest method of doing this is to proceed as outlined above for the compensation of a voltmeter, namely, to add enough series resistance of low temperature coefficient to make the instrument (considered as a millivoltmeter) independent of temperature. The shunts should be of manganin, or other alloy having similar properties. In order to secure a close approach to compensation for temperature in this way, it is usually necessary to increase the full-load drop across the shunt to, say, 150 or 200 millivolts. This method of temperature compensation is the one ordinarily used by American makers.

Another method ²⁸ is used to some extent abroad. A small amount of resistance of low temperature coefficient is added to the moving-coil circuit, and the whole is shunted with a coil of copper or other material of high temperature coefficient. To this branched circuit is then added a certain amount of resistance wire of low temperature coefficient. When the proper relations exist between the resistances and temperature coefficients of the various parts the instrument will be compensated for temperature as a millivoltmeter. This plan has the advantage over the method of plain series resistance, in that the temperature compensation may be secured with a considerably lower voltage for full-scale deflection, and hence the shunts are smaller and less expensive. The method has the disadvantages of being more complicated and of requiring greater care in construction, and the instrument so compensated as a millivoltmeter may have an appreciable temperature coefficient if used as a milliammeter.

(e) **TEMPERATURE COEFFICIENTS OF MOVING-IRON INSTRUMENTS.**—In the moving-iron ammeter, with spring control, an increase of temperature affects the magnetic conditions in the iron in such a way as to decrease the operating torque by about the same percentage that it reduces the spring strength. These ammeters thus are very nearly independent of room temperature changes.²⁹ The temperature coefficient of a moving-iron voltmeter thus depends mainly upon the ratio of the resistance of the copper coil to the total resistance of the instrument. For example,

²⁸ Hallo and Land, *Elektrische und Magnetische Messungen und Messinstrumente*, p. 259.

²⁹ This statement is based on the experience of this Bureau with several instruments of each of two prominent American makes. It is not certain that it applies to all types and grades of moving-iron ammeter.

if the copper coil has a resistance of 150 ohms, and the series resistance of alloy of low temperature coefficient (such as constantan) makes up a total of 1,500 ohms, the voltmeter will read lower by one-tenth of 0.4 per cent, or 0.04 per cent, for an increase of temperature of 1°C .

(f) **TEMPERATURE COEFFICIENTS OF ELECTRODYNAMOMETER INSTRUMENTS.**—In an electro-dynamometer ammeter, with the fixed coil and the moving coil in series, the only appreciable effect of temperature on the reading is that caused by change in the strength of the controlling springs. An increase of temperature of 1°C will reduce the strength of the springs by 0.04 per cent. For any given relative position of the coils, the operating torque varies as the square of the current; the scale, however, is marked to read the first power of the current. Such an instrument will therefore read 0.02 per cent higher on a given current for each degree C of temperature elevation. Hence, if a milliammeter of this type, of suitable range, be supplied with a series resistance of low temperature coefficient, such that the total resistance is twenty times the resistance of the copper windings, the temperature coefficient of resistance of the circuit will be 0.02 per cent per degree C and will offset the effect of temperature changes on the strength of the springs. The instrument will be compensated for temperature as a voltmeter.

A similar condition, namely, total resistance equal to approximately ten times the copper resistance, applies to the potential circuit of an electro-dynamometer wattmeter, if the readings of the wattmeter are to be independent of temperature changes. The torque of a wattmeter is proportional to the first power of the quantity it measures, for any given relative position of its coils.

(g) **TEMPERATURE COEFFICIENTS OF INDUCTION INSTRUMENTS.**—In the induction ammeter of the shifting-field type the use of a noninductive copper coil in parallel with the magnetizing coil has already been referred to (p. 16) as giving approximate correction for both frequency and temperature changes. The rotary-field induction ammeter is also designed to be independent of temperature, as are also induction voltmeters. A low temperature coefficient is more difficult to obtain in the case of induction wattmeters. For this purpose it is necessary to use a special alloy instead of aluminum for the moving element, thus decreasing the ratio of torque to weight. (See p. 47.)

(h) **TEMPERATURE COEFFICIENTS OF HOT-WIRE INSTRUMENTS.**—In the hot-wire instrument a change of room temperature changes the length

of the working wire, and also changes the distance between the supports of the ends of the wire. Hence, if the base plate carrying these supports be made of material having the same temperature coefficient of expansion as the working wire, this source of temperature error in the instrument will be removed. The instrument thus constructed may, however, still have a temperature coefficient caused by changes in the rate at which energy is lost from the wires by radiation and convection with changing room temperature. In the hot-wire ammeter an appreciable amount of heat also escapes by conduction to the end supports and to the flexible strips used to divide the wire electrically into several sections.

(i) **TEMPERATURE COEFFICIENTS OF ELECTROSTATIC INSTRUMENTS.**—Room temperature effects in electrostatic instruments resemble those in the electro-dynamometer ammeter with fixed coil and moving coil in series. The operating torque for a given voltage will be practically independent of temperature. If the moving element is hung on a phosphor-bronze strip, the torque of this strip (for a given angle of twist) will be 0.04 per cent less for each degree C rise. Hence, such a voltmeter, if correct at a given room temperature, will read 0.02 per cent too high for each degree C rise.

(j) **TEMPERATURE COEFFICIENTS OF WATTHOUR METERS.**—In the direct-current watthour meter of the Thomson type the retarding torque is due to the eddy currents set up in the copper or aluminum disk. An increase of temperature of 1°C increases the resistance of the disk 0.4 per cent, and if this effect were not compensated, the speed of the meter on a given load would be increased by this percentage. Compensation is secured by using wire of high temperature coefficient for the series resistance in the armature circuit, so that the armature current decreases as the temperature increases. Some foreign makers use constantan wire for the series resistance, thus producing a meter whose readings vary greatly with room temperature. This state of things is due to the absence of proper performance specifications for meters in the given localities.

In the induction watthour meter both the driving torque and the retarding torque are occasioned by eddy currents in the disk, and as both are weakened alike by an increase of resistance of the disk, the speed of the meter is independent of the temperature of the disk. In stating the torque of such meters, the temperature at which the torque was determined (or the temperature to which the observed value was reduced) should be given.

In both the above cases there are other factors which affect the temperature coefficient of the meter; for example, the change in the permanent magnets. These other factors are minor ones in comparison with those discussed above.

3. EFFECTS OF SELF-HEATING OF INSTRUMENTS

(a) **GENERAL DISCUSSION.**—In the preceding discussion of effects of room temperature it has been assumed that temperatures within the instrument were the same throughout. If no source of heat existed in the instrument this would be very nearly the case. Most instruments, however, contain sources of heat, usually coils of wire through which currents flow. Unequal heating is therefore possible, and an error may result which will depend upon the value of the current or voltage under measurement and upon the length of time that the instrument is kept in circuit.

In direct-current millivoltmeters and in voltmeters of moderate range (say, not over 300 volts) the amount of power converted into heat is relatively small. In alternating-current voltmeters and the voltage circuits of wattmeters the resistance for a given voltage is much lower, and the amount of heat liberated per second is much greater. As a large part of this heating occurs in the dead resistance in series with the working element, this heat-producing resistance should be partitioned off from the working system and properly ventilated.³⁰

(b) **SELF-HEATING OF SHUNTED DIRECT-CURRENT AMMETERS.**—In direct-current ammeters with external shunts there is practically no self-heating within the instrument. The heating of the shunt may be considerable at full load.³¹ While the alloys used in shunts are commonly such as have very small temperature coefficients, there is another important property which must not be overlooked, namely, the thermal electromotive force of the alloy against the brass or copper used for the shunt blocks. The alloy constantan has some properties that make it desirable for shunts, from the standpoint of ease of manufacture, but it has a very large thermal electromotive force which makes it objectionable. Constantan is known also by various trade names, such as Ia Ia, advance, eureka, and others. For the construction of coils of high resistance, such as voltmeter multipliers, constantan has some advantages over manganin.

A considerable part of the heat produced in switchboard ammeter shunts is carried away by conduction to the bus bars, from which it escapes by

³⁰ Neglect of this precaution usually results in an instrument which can not be left in circuit for any appreciable time without introducing an appreciable error due to internal heating.

³¹ See paper by Fitch and Huber, *Bulletin of the Bureau of Standards*, 7, p. 412; *Scientific Paper No. 163*.

radiation and convection. Even if the opportunity for escape of heat is the same at each end of the shunt, there will still be a difference of temperature. This is caused by the flow of current through a circuit made up of dissimilar metals, and is known as the Peltier effect. It causes a thermal electromotive force in such a direction as to increase the reading of the ammeter. In cases of unequal heating of the two ends of the shunt, caused by bad contacts or by difference in size of bus bars, the resultant thermal electromotive force may either increase or decrease the reading of the ammeter.

Thermal electromotive force may be detected by allowing the current to flow until the shunt has reached its maximum temperature elevation, and then breaking the main circuit, when the index will fail to return to zero if appreciable thermal electromotive force is present. This effect may be distinguished from zero shift (due to spring fatigue) by disconnecting one lead from the instrument, when the position of the index will change by an amount proportional to the thermal electromotive force.

(c) **USE OF COPPER BAR AS AMMETER SHUNT.**—The use of portions of copper bus bar as ammeter shunts is not now recommended on account of the large temperature errors due to heating of the bus bar by the current. In special cases, where a length of bus bar is available which gives a drop at full load of several times that required by the instrument, a fine insulated copper wire can be laid along the bar in intimate heat contact with it, and used as a series resistance in the millivoltmeter circuit. The heating of this wire will tend to compensate for the increased drop on the shunt as the latter heats up. This method is limited by the necessity of avoiding joints in the part of the bus bar used as a shunt and by the uncertainty as to the distribution of current between the separate bars of a laminated bus.

(d) **SELF-HEATING OF PORTABLE DIRECT-CURRENT AMMETERS.**—Portable direct-current ammeters have been made with internal copper shunts, in order to reduce the loss of power in the instrument. As both shunt and moving coil are of copper, changes of room temperature will not alter the relative distribution of current between moving coil and shunt. As the temperature coefficient of the unshunted instrument as a milliammeter is quite small, such a shunted instrument would be a very good one were it not for self-heating of the shunt and the resulting differences of temperature within the instrument. In the smaller sizes (say, up to 15 amperes) such instruments give a good performance, but as the ampere capacity increases the performance becomes poorer, until in capacities of 300 to 500 amperes

the indications change very rapidly after closing the circuit, and the instruments are not suitable for any but rough work.

(e) **USE OF MANGANIN FOR AMMETER SHUNTS.**—For precision ammeter shunts, manganin is usually regarded as the most satisfactory material that is supported by a long service record. Manganin is an alloy of about 84 per cent copper, 12 per cent manganese, and 4 per cent nickel. Its specific resistance is about 25 times that of copper, and its temperature coefficient and thermoelectric power against copper are both very small. Two other alloys with properties similar to those of manganin have been in use for a shorter time and seem to give promise of good permanence; one is an American product which bears the trade name of *therlo*, and the other a German alloy known as *Kulmiz alloy*, or *Achenrain resistance material*.

(f) **SELF-HEATING OF MOVING-IRON INSTRUMENTS.**—In the moving-iron ammeter the conditions are favorable for a small error due to the effect of internal heating, since the power lost in the instrument (if the latter is well designed) is small, and the iron and the spring are usually near each other, and hence their temperatures will not differ greatly under any circumstances. In the moving-iron voltmeter the conditions are slightly less favorable, as the heating of the copper coil increases the resistance of the circuit.

(g) **SELF-HEATING OF HOT-WIRE INSTRUMENTS.**—The matter of internal heating in the hot-wire instrument is unique, in that the operation of the instrument depends on internal heating. However, some questions arise in this connection. For example, the base plate carrying the supports for the hot wire will be heated by the hot wire, and this heating will be very slow, on account of the heat capacity of the base plate. If a hot-wire instrument is to be kept in circuit continuously, it ought to be tested only after having been in circuit long enough to reach a steady state.

No energy losses occur in the electrostatic instrument, and hence it is free from errors due to internal heating.

(h) **SELF-HEATING OF THOMSON DIRECT-CURRENT WATTHOUR METERS.**—An interesting example of the effect of self-heating on accuracy is that afforded by the Thomson type of direct-current watthour meter. The accuracy curve for such meters rises between 10 per cent load and about half load, then droops for all loads above half load. This effect, which was long thought to be due to the counter electromotive force of the armature, has been shown²² to be due largely to the increased resistance of the armature when the latter is heated by the series coils.

²² Fitch and Huber, Comparative Study of American Direct-Current Watthour Meters, Bulletin of the Bureau of Standards, 10, p. 188, 1913; Scientific Paper No. 207.

4. EFFECTS OF STRAY MAGNETIC AND ELECTROSTATIC FIELDS

(a) GENERAL DISCUSSION.—The effect of stray magnetic field upon the indications of an instrument depends on the nature of the field and the operating principle of the instrument. A magnetic field of constant direction and magnitude, such as is produced by a direct current in a conductor, or by an electromagnet excited by direct current, will in general affect the indications of the following types of instrument: Permanent-magnet moving-coil; moving-iron; and electro-dynamometer. It has been shown³³ that such a stray field changes merely the strength of the magnetic field in the air gap of a permanent-magnet moving-coil instrument, but not the distribution of this latter field. The error due to the stray field will therefore be a constant percentage of the indication of the instrument, so long as the disturbing stray field is constant in amount and direction. It is usually recommended that when portable instruments must be used in places subject to strong stray fields the mean of two readings be taken, the instrument being turned 180° about the axis of rotation of the moving element for the second reading. In the case of permanent-magnet moving-coil instruments, another method consists in placing the instrument with its magnetic field at right angles to the direction of the stray field, the latter being determined by the use of a compass. In this position the effect of the stray field will be small, and changes in the *magnitude* of the stray field are not important. It is, of course, better to avoid exposing instruments to stray fields as far as possible. In the case of moving-iron and electro-dynamometer ammeters and voltmeters it is better to leave the instrument in one position and take the mean of two readings, the current through the instrument being reversed for the second reading. However, these latter instruments should in general not be used for direct-current work, if permanent-magnet moving-coil instruments are available.

Stray fields due to direct currents have no effect (or a very small effect) on instruments of the hot-wire, electrostatic, and induction types.

If the stray field is due to an alternating current, no perceptible effect will be observed on the reading of a permanent-magnet moving-coil instrument, unless the stray field is strong enough to demagnetize the permanent magnet to some extent. This will cause the instrument to read low until it is repaired. An extreme case of this kind is given³⁴ in which a direct-

³³ Heinrich and Bercovitz, *Handbuch der Elektrotechnik*, 2, pt. 5, pp. 9-11.

³⁴ E. P. Peck, *Electrical World*, 51, p. 1220; 1908.

current voltmeter was connected to a 600-volt circuit and placed within 18 inches of heavy bus bars. After a severe short circuit, which caused very heavy alternating currents to flow for an instant through these bars, the voltmeter read 350 volts when the applied voltage was 600.

MacGahan, in Proceedings of the National Electric Light Association for 1913, page 602, shows an instrument of the permanent-magnet moving-coil type having a single air gap which is stated to be practically unaffected by strong stray fields due to the current in a vertical conductor. The arrangement is such that the stray field passes through the magnet at right angles to the permanent flux.

It is doubtful whether any general rule can be given for determining the error due to stray magnetic field in the use of portable moving-iron instruments. Some makers surround the operating system with a magnetic shield of laminated soft iron as a protection against stray fields. This affords considerable protection, but adds appreciably to the weight of the instrument, and sometimes gives trouble when the instruments are used on direct current, on account of magnetic polarity which may develop in the iron shield.

Moving-iron instruments of the switchboard type are partially shielded from stray magnetic fields by the iron cases in which they are usually mounted. However, they should be placed so as to avoid stray fields as far as possible.

Electrodynamometer ammeters, voltmeters, and wattmeters, as usually made, are appreciably affected by stray magnetic fields. Such instruments are usually tested with direct current, and in order to eliminate the error caused by the earth's field, which may amount to 1 or 2 per cent of the maximum scale reading, it is necessary to take the mean of two readings, the direction of the current through the instrument being reversed for the second reading. It is usually possible to find a position of the moving coil such that the earth's field produces no effect on the reading; that is, for the given position of the instrument and the given scale reading, the moving coil incloses the maximum possible number of lines of force due to the earth. When such an instrument is used on alternating currents, stray fields such as the earth's, which do not change in direction, have no effect on the reading, but errors may be caused by the stray fields set up by large alternating currents whose frequency is the same (or nearly the same) as that of the currents in the instrument. To avoid this, all leads to the instrument and near the instrument should be run as noninductively as possible, by avoiding

loops. The use of a magnetic shield of laminated iron surrounding the movement is becoming more general. In testing such instruments with direct current, the mean of reversed readings should be taken in order to eliminate any effect caused by magnetic polarity in the shield.

Hot-wire and electrostatic instruments are practically unaffected by stray alternating fields, though a slight error from this cause is theoretically possible.

(b) **ASTATIC INSTRUMENTS.**—The preceding discussion applies to simple instruments of the various types. To avoid the effects of stray fields, astatic instruments are made by combining two operating systems, or their equivalent. For example, two permanent-magnet moving-coil systems are used, with the moving elements coupled to add their torques and with the two magnets arranged to have opposite polarities. Another astatic arrangement consists of two moving-iron systems coupled to operate a single index, the polarities of the two solenoids being opposite. Both the above are used in foreign recording instruments. An astatic electrodymanometer instrument contains two moving coils rigidly connected, with their polarities opposite, so that with direct current flowing in them, for example, the force due to the earth's field acting on one coil is balanced by the force on the other coil. This construction is not used as much as it deserves to be, probably on account of increased mechanical difficulties of construction. In another form of astatic instrument, applicable only to direct current, the deflecting torque and the controlling torque are both caused by the same magnetic field. This field is produced by an electromagnet supplied from a separate source or by means of a permanent magnet.

A word of caution is necessary concerning astatic instruments. They are much less affected by stray fields than the ordinary types, but they are strictly astatic only for fields which are uniform over the space occupied by the coils, or for nonuniform fields which may happen to produce the same torque on each coil. The field about a bus bar carrying a current is not uniform, but decreases in intensity as the distance from the bar increases. If an astatic instrument is placed near the bar, one coil of the astatic system may be so much closer to the bar than the other as to give an appreciably greater force on the nearer coil, and hence a residual error will be caused by the stray field. In using astatic instruments the same precautions should be taken as for simple instruments, if the maximum accuracy of which they are capable is desired.

(c) **ERRORS DUE TO ELECTROSTATIC ACTION.**—Stray electrostatic fields can produce no effect on an instrument wholly inclosed in a metal (conducting) cover. Electrostatic effects are therefore limited, as a rule, to those due to fields set up within the instrument. Rubbing the cover glass over the index will often cause the index to move from its proper position, due to the action of an electric charge produced on the glass. One remedy for this consists in breathing on the glass, the moisture causing the induced charge to disappear. Another electrostatic effect may be noticed when testing wattmeters by the method of separate sources of current and voltage. When the potential of the fixed coil is different from that of the moving coil, an electrostatic force is exerted between the two which may cause appreciable errors in the indications. The remedy is to arrange the circuits so that the fixed coil and the moving coil may be joined at one point. This requires care to avoid trouble, due to a possible contact between the circuits at some other point.

This connection between the coils may well be made through a direct-current voltmeter whose maximum reading is not less than the voltage used in testing the wattmeter. The index of this voltmeter should remain at zero; if a deflection occurs, leakages or contacts are present in the test circuits.

Instruments having a wooden baseboard and metal covers are liable to error from electrostatic forces between the index and the metal case. During a test of a direct-current voltmeter at 750 volts, variations of 4 or 5 divisions in the reading were observed when the observer touched the metal case.

Induction instruments have nearly closed magnetic circuits and strong working fields. They are consequently much less affected by stray alternating fields than unshielded instruments of the moving-iron and electro-dynamometer types, and are not affected by direct-current fields.

5. EFFECTS OF IMPERFECT ELASTICITY OF SPRINGS

(a) **GENERAL DISCUSSION.**—The quality of the springs used in an electrical instrument has an important bearing on the accuracy of the results obtained. At one time springs were looked upon with suspicion, and "gravity-controlled" instruments were often preferred. These are still made by foreign makers, most of whom also supply instruments with spring control. Gravity-controlled instruments are somewhat cheaper in first cost. While present-day springs should not be looked upon as free from the

possibility of change with time, those used by the best makers give very good results, and may be considered to be no more liable to change than other parts of the instruments.

(b) **ZERO SHIFT.**—If the index of an instrument stands at zero with no current flowing, after an interval of, say, several days of rest, and the circuit be closed so as to give full-scale deflection for a few minutes, then on breaking the circuit the index will usually return to zero, within the limit of reading. If full-scale deflection be maintained for an hour, the index will probably not return exactly to zero on breaking the circuit. If the deflection be maintained for several hours, the discrepancy will be still greater. This zero shift is due to elastic fatigue or viscosity; it is only temporary, and gradually disappears. The amount of this zero shift varies not only with the procedure of use, as just outlined, but also varies in different classes of instruments and in different individuals of the same class. In first-class voltmeters it should not be more than just noticeable (say, 0.1 division). In millivoltmeters it is usually greater, although occasionally a millivoltmeter will show very good performance in this respect.³⁵ The effect of zero shift upon the accuracy of the results (if the shift be not allowed for) is greater when an instrument is used for a small deflection soon after it has sustained a large deflection for a considerable time.

The amount of zero shift depends also on the design of the spring; this matter is referred to later. (See p. 48.)

Another form of zero shift is caused by the gradual change of form of springs with time. This has been observed in a number of instruments using a single spiral spring, and the change observed was evidently a gradual uncoiling of the spring. In moving-coil instruments it is customary to use two spiral springs wound in opposite directions. In this case the tendency of one spring to unwind would offset a similar tendency in the other spring.

The zero shift, due to thermoelectric effects, is considered on page 34.

(c) **HOOKE'S LAW.**—It has often been assumed that the torque of a spiral spring is exactly proportional to the angle of twist; in other words, that the spring obeys Hooke's law. Hence, in testing such instruments as the Siemens dynamometer, the "constant" of the instrument was determined for one value of current and assumed to hold for any other value, or

³⁵ The reason for the poorer spring performance of millivoltmeters, as a class, lies in the necessity of using springs which approach pure copper in electrical conductivity; such springs tend toward the greater elastic viscosity of pure copper. For voltmeters this limitation as to conductivity does not exist, and the springs may be made of any alloy which is non-magnetic and has the best mechanical and elastic properties. Phosphor bronze of good quality is usually considered to be a very satisfactory material.

the constant was taken as the mean of several determinations with different currents. This assumption has been shown to be incorrect and to lead to errors of 1 per cent or more.³⁶ In ordinary direct-reading instruments, with properly calibrated scales, such an error does not appear. However, if by accident the spring should be thrown out of its original shape, the scale will no longer be correct, even though by shifting the spring holder the index be brought back to zero. If the spring is considerably distorted, the instrument should be sent to the maker for repairs.

(d) **ZERO ADJUSTMENT.**—It is becoming more general to provide zero-adjusting devices for indicating instruments, and such devices are very good if properly used. They may be used to correct for small variations of the springs, but should not be used to bring to zero a pointer that has been bent, as such an adjustment brings the moving part into an initial position different from that which it occupied when the original calibration was made. In instruments which do not have a uniform scale this may introduce appreciable errors throughout the scale.

6. EFFECTS OF FRICTION AND LACK OF BALANCE

(a) **FRICTION OF PIVOTS.**—In a properly designed and well made instrument the friction of pivots should not affect the readings appreciably, unless the instrument is old or has been roughly handled. Good performance as regards friction requires not only good workmanship in the pivots and jewels but also good design. (See p. 47.) In general, it is preferable to have the axis of rotation vertical in pivoted instruments, as the friction will be smaller and more uniform than with a horizontal axis. This principle may be departed from in switchboard instruments, which need not be read with great refinement, but the vertical axis is to be used for precision instruments.

Friction at points other than the pivots often makes the readings so irregular as to call attention to the trouble and to make the instrument useless until the difficulty is removed. In some cases, however, friction of this kind may affect the readings only at certain times, and usually at certain parts of the scale, and the trouble may be difficult to discover. Such friction is sometimes caused by fine fibers loosening from the substance of the paper scale and projecting out till they touch the index. Similar trouble may be caused by small particles of foreign matter getting into the air gap of a direct-

³⁶ Wm. Bradshaw, *Electric Journal*, 3, p. 395; 1906.

current instrument or into the air-damping box of an alternating-current instrument.

(b) **LACK OF BALANCE OF MOVING SYSTEM.**—If the moving system of a spring-controlled instrument is not properly balanced, the indications of the instrument will vary with change of level of the instrument. Errors due to this cause may be considerable. To investigate a portable instrument in this respect, it should be tipped say 10° from the horizontal; a switch-board instrument should be held with the axis of rotation of the moving system approximately horizontal, and should be slowly turned through 360° about this axis. The instrument should be disconnected from the circuit while this is done. Millivoltmeters, wattmeters, and alternating-current instruments, most of which usually have a smaller ratio ³⁷ of torque to weight than the direct-current voltmeter, usually show somewhat more deviation than the latter. If a portable instrument shows considerable variation of zero reading, when examined as above, care should be taken to have it on a level support when in use as well as when it is being tested. At a convenient opportunity the moving system should be balanced; this should preferably be done by the maker.

7. EFFECTS OF SOME CONSTRUCTIONAL DETAILS ON ACCURACY

(a) **INSTRUMENT SCALES.**—At one time instrument scales were engraved or printed, on the assumption of a particular law for the given type; generally the individual instruments were then adjusted by trial to make them fit the scale as closely as possible. Such a method does not give good results, in general, and it is now the usual practice to make an individual scale for each instrument. It is not necessary, of course, to determine every scale division by test, especially in direct-current instruments with nearly uniform scales. It is usually considered sufficient to determine 10 or 15 points of the scale of a direct-current instrument by actual test. The intermediate points are filled in, sometimes by hand, preferably by a mechanical method. The accuracy claimed for the scales of high-grade portable direct-current instruments is usually one-tenth ³⁸ of a scale division ($1/1500$ to $1/1000$ of a right angle). This refers to the error at any point on the scale, assuming that the resistance adjustments of the instrument are such as to reduce the error of the indications to a minimum. The remaining errors may then be charged to inexactness of graduation of the scale.

³⁷ See discussion of this ratio on p. 47.

³⁸ To attain such an accuracy requires great care and good facilities.

Alternating-current instruments with nonuniform scales require the determination of a larger number of points of the scale by test, if an accurate scale is required.

(b) **RESISTANCE ADJUSTMENT.**—Errors due to inexact adjustment of the resistances of an instrument affect all the readings of the scale by the same percentage, and may be removed by making an exact adjustment of resistance. Multiple-range instruments may have errors of resistance adjustment which are negligible on some ranges and appreciable on others. Multiple-range voltmeters may be checked in this respect by measurements of resistance, using a Wheatstone bridge. This method is not applicable to multiple-range ammeters, as the sensitivity and accuracy of the Wheatstone bridge are not adequate when such low resistances as those of ammeter shunts are to be measured.

(c) **TEMPERATURE COMPENSATION.**—An instrument may be nominally compensated for temperature, but the compensation may not be good enough for some classes of work. This defect will not appear in the use of the instrument at a uniform room temperature, but may introduce an error too great to be tolerated when instruments are unavoidably used in extremes of temperature. An illustration is the use of an ammeter to measure the current taken by the incandescent lamp in a portable photometer or illuminometer. Here an error of 1 per cent in the current will make, say, 5 per cent error in the measurement of the candlepower, and as the instrument may be used outdoors, extreme temperatures may be unavoidable. For work of this kind where accuracy is essential, the temperature coefficient of the instrument should be determined.

8. PERMANENCE OF CALIBRATION

Permanent magnets, as now made by careful makers, show a very good constancy under normal conditions; that is, when the magnetic circuit is properly designed³⁹ and the instrument is not roughly handled or abused by exposure to strong magnetic fields, extremes of temperature, or severe overloads.⁴⁰

In the above discussion of changes in magnets and springs it has been assumed that the windings of the instrument did not change with

³⁹ See discussion of this subject on p. 48.

⁴⁰ In several cases which have been noted, a change of several per cent in the indications of permanent-magnet moving-coil instruments could only be explained by the fact that through improper connections a current many times greater than normal had been momentarily passed through the moving coil, thus permanently affecting the strength of the magnet.

time. This is usually the case, but it is preferable to check the values of resistances of instruments at intervals of, say, six months or a year, depending on the conditions of use.

9. CONDITIONS AND MANNER OF USE

The result of a measurement with indicating instruments always involves the personal element, over which the instrument maker has no control. A few suggestions will now be given in regard to the care and use of instruments.

(a) CARE IN HANDLING.—Electrical instruments are essentially delicate; their operating forces are small, and their accuracy depends upon great refinement of construction, especially in such parts as pivots and jewel bearings. They should therefore be handled carefully, and not exposed to unnecessary vibration, moisture, or extremes of temperature. Portable instruments should be placed on a level support, and not too near each other, as they may affect each other's readings by 1 per cent or more if placed near together. If cover glasses must be wiped clean before taking readings, the observer should breathe on the glass to dispel any static charge which might be present.

Good contacts are essential to accurate measurements. This is especially true in the use of millivoltmeters with separate shunts. There are four contacts in the connections between shunt and instrument, and the resistance of the instrument is only a few ohms; a corroded or dirty terminal or binding-post surface may introduce errors of several per cent.⁴¹

(b) POWER LOSSES IN INSTRUMENTS.—When measurements of small electrical quantities are made, for example, the iron loss in a small transformer, it becomes important to avoid (or correct for) errors due to the power required to operate the instruments. For example, the ordinary electro-dynamometer wattmeter can be connected to measure a load, either with the voltage circuit in parallel with the load, in which case the reading includes the power required by the voltage circuit of the wattmeter, or with the voltage circuit connected on the source side of the wattmeter, in which case the reading includes the power required by the current circuit of the wattmeter. Similar conditions arise in many cases where several instruments are used in a given measurement.⁴²

⁴¹ Such terminals and binding posts should be nickel plated, and the maker's instructions might well lay more stress on the matter of clean surfaces and firm connections.

⁴² Jansky, *Electrical Meters*, 1st edition, pp. 118 and 357; Taylor, *Electric Journal*, 2, p. 476, 1905.

Compensated wattmeters have an auxiliary series winding; when properly constructed they avoid the necessity for correction for instrument losses.

Errors due to variations of frequency, when such variations are relatively large, are best avoided by using types of instrument which are inherently but little affected by frequency changes. The same is true of waveform variation, which is, to a certain extent, analogous to variation of frequency. Fortunately, the tendency of design of modern alternators is toward the sine wave form, and the frequency in at least the larger modern plants is usually closely controlled.

The error of reading depends upon the construction of the instrument, the skill of the observer, and the steadiness of the quantity under measurement. Precision indicating instruments are generally provided with an index having a flattened end, and a mirror beneath the pointer to avoid error due to parallax. With a well-made instrument of this sort it is possible for a skilled observer to make a reading to about 0.1 mm, or 0.1 division on a uniformly divided scale of the usual length. This refers to the condition of steady current; on commercial circuits, where fluctuations occur, the precision of reading is not so good.

VII. NOTES ON THE DESIGN OF ELECTRICAL INSTRUMENTS

1. CONFLICTING REQUIREMENTS OF DESIGN

In all electrical design some compromises must be made. If the attempt is made to design a transformer of given output having very low copper losses, it will be found impossible to keep the iron losses as low as could be done in a better balanced design. If an incandescent lamp is designed to operate at an unduly high temperature, the life will be short.

Most electrical instruments have the disadvantage of small operating forces, and thus not only require very good workmanship, but more care in handling than many other measuring devices. If the design is modified so as to increase the operating forces, the power lost in the instrument may be increased, thus increasing the correction which must be made on this account. Another drawback is the increased heating, which tends to introduce errors.

2. EFFECT OF SERVICE CONDITIONS ON DESIGN

The nature of the service has an important bearing on design. In many kinds of switchboard instruments it is preferable to design for relia-

bility and ruggedness, even at the expense of reducing the accuracy, in order that the instruments may not be damaged by handling, by vibration, or by occasional momentary short circuits. Standard instruments for laboratory use must be designed to give the required degree of accuracy. They may be more delicate than portable instruments and may require greater care in handling.

3. RATIO OF TORQUE TO WEIGHT OF MOVING ELEMENT

Even with the most careful workmanship in pivots and jewels, friction can not be entirely eliminated. The springs should therefore be strong enough to cause the coil to take up its proper position within the minimum error of reading. According to one writer ⁴³ the torque for full-scale deflection, expressed in centimeter-grams, should not be less than one-sixth of the weight of the coil in grams. Other writers ⁴⁴ give a considerably lower minimum value, namely, one-twentieth. In both these cases a deflection of approximately 90° is assumed, this being the usual full-scale deflection for most direct-current instruments. In this country it is perhaps more usual to express the torque of electrical instruments and meters in millimeter-grams; this gives a number for the ratio of torque to weight which is ten times as large as when the centimeter-gram is used. Using the millimeter-gram, the rule given by Janus becomes "torque must not be less than five-thirds of the weight in grams," and the rule given by Heinrich and Bercovitz becomes "torque must not be less than half the weight in grams." It is desirable to keep the ratio of torque to weight as high as possible, without unduly sacrificing other qualities. It should be noted that an instrument of very high torque may be a poor instrument if the high torque is obtained by using an excessively heavy moving element.

It is desirable to have a high ratio of torque to weight in watthour meters, as this tends toward good performance at light load. In American direct-current meters of the Thomson type, as now made, this ratio ⁴⁵ (using the millimeter-gram and gram) will average a little over unity; in American induction watthour meters this ratio is more favorable, being about two to four times as great as for direct-current watthour meters.

⁴³ Janus, *Elektrotechnische Zs.*, 28, p. 560; 1905.

⁴⁴ Heinrich and Bercovitz, *Handbuch der Elektrotechnik*, 2, pt. 5, p. 14.

⁴⁵ Fitch and Huber, Study of American Direct-Current Watthour Meters, *Bulletin of the Bureau of Standards*, 10, p. 171; 1913, Scientific Paper No. 207.

4. PERMANENCY FACTOR OF THE MAGNETIC CIRCUIT.

A general principle applying to permanent magnets used in instruments and meters is that the magnetic circuit should be as nearly closed as possible. The following empirical relation was first given numerically by Hookham ⁴⁶ in 1888. He stated that if A equal the area of cross section of the air space, L the distance between the pole pieces, a the cross section of the magnet, l the length of the magnet (mean length of the lines of force in the permanent magnet), then $A \div L$ should equal about 70 times $a \div l$. This ratio of $A \div L$ to $a \div l$ may be called the permanency factor of the magnetic circuit. Heinrich and Bercovitz ⁴⁷ restate Hookham's formula, but say that the permanency factor should not be less than 100. In the usual bipolar construction of permanent-magnet moving-coil instruments, L is equal to the sum of the lengths of the two air gaps, or in general, it is the total length of air gap.

The Hookham permanency factor of a magnet is a purely geometrical relation and does not take into account other matters which affect the permanency, such as composition of steel, heat treatment, aging treatment, and the flux density in the finished magnet. It is, however, a useful guide in design.

5. DESIGN OF SPIRAL SPRINGS.

The zero performance of a spring depends not only on the material and method of treatment, but on its dimensions and the angle through which it is twisted in use. Formulas for spring design ⁴⁸ are given by Janus and by Edgcumbe.

6. MECHANICAL DETAILS

The mechanical construction should be such as to assure the permanent relation to one another of the various parts of the instrument. The moving parts should be inclosed in a dust-tight case, and for special uses may have to be water-tight.

The use of hard rubber in electrical instruments has the drawback of causing corrosion of springs and fine wires. Soft-rubber tubing should be avoided, as fine connecting wires covered with it are corroded by the free sulphur, sometimes resulting in open circuits. It is preferable to use treated cotton sleeving.

⁴⁶ On Permanent Magnets, by George Hookham, *Philosophical Magazine*, fifth series, 27, p. 186; 1889.

⁴⁷ *Handbuch der Elektrotechnik*, 2, pt. 5, p. 29.

⁴⁸ Janus, *Elektrotechnische Zs.*, 26, p. 560; 1905. Edgcumbe, *Industrial Electrical Measuring Instruments*, p. 16. The latter states that for phosphor-bronze springs which are to be deflected 90° the length of the spring must be at least 1500 times its thickness.

(a) SWITCHBOARD SHUNTS.—The limitations as to space and cost imposed on switchboard ammeter shunts apparently make it impractical to design them with the precautions which are needed for precision work, especially in shunts for large currents. In the latter, changes ⁴⁹ of several per cent in the effective resistance of the shunt may sometimes be caused by changes in the method of attaching the copper bars to the shunt. Shunts for precision purposes should have the terminal blocks longer, so as to make the lines of current flow more nearly parallel at the junction of the terminal block and the resistance metal, near which junction the potential terminals should be located. The same result may be attained by constricting the section of the terminal block considerably between the current terminal and the potential terminal.⁵⁰

VIII. TESTING OF ELECTRICAL MEASURING INSTRUMENTS

1. NECESSITY FOR TESTING OF INSTRUMENTS

Since electrical instruments which are carried about and used at times under unfavorable conditions are liable to change, means should always be provided for their periodical testing. It is important to check switchboard instruments, not only when they are received from the maker, but also regularly after they are mounted. This periodical checking should be done without dismounting the instruments from the positions in which they are used, in order that their errors under working conditions may be determined. The portable instruments used in such checking should be placed so as to be as little exposed to stray field as possible. This condition may be shown to exist by turning the portable instrument through 180° and noting that the reading is not appreciably changed by the change of position. It has been shown ⁵¹ that the removal and replacement of the pole pieces of a direct-current instrument—in fact, even the tightening of the screws that hold the pole pieces—may affect the distribution of the magnetic flux so that a scale which fitted the instrument before the operation will now show appreciable errors. It is clear from this that any mechanical change, adjustment, or accident to an instrument should be followed by a test.

Fundamental electrical standards, with a few exceptions, are for direct current. The most accurate method of measuring direct current and

⁴⁹ Rosa, *Trans. Am. Inst. Elec. Engineers*, 24, p. 223; 1905.

⁵⁰ For a discussion of the design of shunts, see Wenner, *Bulletin of the Bureau of Standards*, 8, p. 577, 1913; *Scientific Paper No. 181*.

⁵¹ Heinrich and Bercovitz, *Handbuch der Elektrotechnik*, 2, pt. 5, p. 3.

voltage is by means of a potentiometer and suitable accessories, and no laboratory for the precision checking of electrical instruments should be considered complete without a potentiometer equipment.

Carefully calibrated deflection instruments are extensively used where the requirements are less exacting. A complete potentiometer installation is expensive and for many small laboratories its cost may be prohibitive. Whatever type of deflection instrument is used, it is good practice to have a reserve instrument to check the working standard in place from time to time, unless it is possible to have the instruments tested in a near-by laboratory to which they can be carefully transported by messenger. Deflection instruments arranged to be checked at one point by reference to a standard cell are made by foreign makers. They have one of the advantages of the potentiometer—namely, that of referring the results to a standard cell, which gives the possibility of using several cells to check one another.

2. POTENTIOMETERS AND THEIR ACCESSORIES

(a) PRIMARY AND SECONDARY STANDARDS.—Primary standards, properly so called, are not suitable for general use, but are maintained in a few well-equipped laboratories.⁵² The instruments used to check service instruments may properly be called secondary standards; they should be checked by a national standardizing bureau, or by such college or other laboratories as are prepared to do this work. The secondary standards to be provided by a central station, public-service commission, or other user of instruments, will depend upon the number and kind of service instruments to be tested, and on the nature of the electrical supply concerned.

(b) PRINCIPLE OF THE POTENTIOMETER.—The potentiometer is an arrangement of resistance coils through which a constant current is maintained by a storage cell. While the arrangement of coils may be rather complicated, in principle it is equivalent to a long wire of uniform resistance per unit length, with two contacts, one or both of which are movable. If these contacts are separated, the difference of potential between them will depend on the length of the wire included between them, on the resistance per unit length, and on the current in the wire. By properly choosing the latter two, the difference of potential between the two contacts may be made an even value, say, 1 millivolt per centimeter of wire. The current

⁵² Primary standards for the United States are maintained by the Bureau of Standards at Washington; those for Germany, by the Physikalisch-Technische Reichsanstalt at Berlin; for England, by the National Physical Laboratory at Teddington; those for France at the Laboratoire Centrale d'Electricite at Paris.

through the wire is adjusted to the standard value by setting the two contacts apart by an amount equal to the certified voltage of a standard cell; this cell is connected, through a key and a galvanometer, in opposition to the voltage between the two contacts. The current is then regulated until, on closing the key, the galvanometer shows no deflection. The standard cell may then be removed, and an unknown voltage put in its place and measured by moving the sliding contacts until the galvanometer again shows no deflection; the value of the unknown voltage may then be read off from the length of wire between the contacts.

The potentiometer thus measures voltage in terms of the electromotive force of a standard cell, which is simply a cell made of pure chemicals of such nature as will give a constant difference of potential between its terminals. While a measurement made with a voltmeter depends on the permanency of the magnet and springs, which can not be checked by the user, the potentiometer has the great advantage that the user can have several standard cells, and may readily substitute one for another as a check, and may compare the values of standard cells. It is recommended that three cells be used; if two of these agree but fail to check with a third, the two may be used while the third is sent to a standardizing laboratory for test. A further advantage of the potentiometer is that its accuracy depends only on the *relative* resistances of its coils, and these relative resistances may be checked by the user.

(c) STANDARD CELLS.—The most convenient standard cell for general laboratory use is unquestionably the Weston portable⁸³ cell of the unsaturated type, as supplied by the Weston Electrical Instrument Co. These cells should be guarded from extremes of temperature, and so far as possible no current should be allowed to flow through them.

(d) VOLT BOXES.—The fundamental range of many potentiometers is 0 to 1.5 volts; the latter value came into use because it was a round figure slightly in excess of the value of the Clark cell; it has doubtless been continued because 150-division instruments are much used, and it is convenient to have the potentiometer range agree numerically with that of the instruments to be tested. It is often convenient to have the fundamental range of the potentiometer slightly greater than 1.5 volts. For measuring volt-

⁸³ The Weston "normal" cell with *saturated* solution and excess of crystals is used by national laboratories because of its reproducibility. On account of its variation in electromotive force with temperature, it is not so well adapted for general use as the unsaturated cell. The Clark cell was formerly much used, but it has an objectionably large temperature coefficient, and also a time lag of electromotive force behind the temperature. There is little reason for using it at this time.

ages in excess of the range of the potentiometer an adjunct called a "volt box" is almost universally used. This is simply a resistance box in which a high resistance is connected to the line whose voltage is to be measured, while the potentiometer is connected across a definite fraction of the resistance, usually one-tenth, one-hundredth, etc. Ordinary resistance boxes of known value may be used as volt boxes for low voltages, but for the usual direct-current lighting and power voltages this practice is not advisable. Volt boxes designed for the purpose should be used; they should have a sufficient number of coils to keep the dielectric stress per coil down to a safe value, and the coils, terminals, and other parts should be properly spaced and insulated for the maximum voltage.

(e) MEASUREMENT OF CURRENT.—A direct current which is to be measured by the potentiometer is passed through a suitable resistance standard. The potentiometer is connected to the potential terminals of the resistance standard and measures the fall of potential across these terminals. This fall of potential, in volts, divided by the resistance of the standard in ohms, gives the value of the current in amperes. Resistance standards for this purpose are usually made of manganin, and may be air-cooled or oil-cooled. The latter method of cooling is used for the most precise laboratory work, as it not only reduces the rise of temperature of the shunt under load, but also makes it possible to determine the temperature of the resistance material more accurately. For commercial work, and for some classes of laboratory work, the air-cooled (Crompton) form of resistance standard gives sufficient accuracy, when properly designed, and avoids the disagreeable features attending the use of oil. Resistance standards for measuring very large currents may require oil immersion, not for the sake of high accuracy, but to reduce their dimensions and cost.

For small currents the resistance standard is usually made to give 1 to 1.5 volts drop at full load. This brings the full-load reading well up in the range of the potentiometer. For large currents it is advisable to use a lower full-load drop, but the reduction of the drop should not be carried too far, or both the sensitivity and the accuracy will be impaired. It has sometimes been stated that the drop on the resistance standard, in precise measurements, can be reduced to very small values, the only limit being the sensitivity of the galvanometer. This is not the case, for even manganin resistance standards show slight thermal electromotive forces, and such electromotive forces often exist in the potentiometer contacts, in the junctions of connecting leads, and in the galvanometer. The resultant of all these

electromotive forces introduces an error which is proportionately greater the lower the drop on the shunt. While it is true that such sources of error may be practically eliminated even with very low shunt drops, this procedure requires the introduction of reversing switches and the multiplication of the readings necessary to be taken. For this reason it is advisable to have a full-load drop of at least 0.1 volt, in which case the thermal electromotive forces may generally be neglected.

It is convenient to have two resistance standards of each denomination, one for regular use and one which is used only to check the other at intervals. If the standards are for immersion in oil, the reserve standard should be immersed only at the times when comparisons of the two are made, as the oil may become contaminated and attack the manganin, thus affecting the value of the standards in the course of time. In case of disagreement, one of the standards may be sent to a standardizing laboratory for test. If the working standard is accidentally overloaded, it should be compared with the reserve standard before it is again used. This comparison may conveniently be made by connecting the two standards in series, passing a steady direct current through them, and measuring with a potentiometer the drop across the potential terminals of each. A quick-throw switch may be used with advantage to shift the potentiometer from the one to the other. A Wheatstone bridge is not suitable for comparing resistance standards of the values ordinarily used for current measurements.

(f) STORAGE BATTERY EQUIPMENT.—To supply the current⁶⁴ for such work as the testing of ammeters, it is convenient to have, say, four storage cells with switches for connecting them in parallel for the maximum current, in parallel series for medium, and in series for smaller currents and for charging. A voltmeter should be provided, with a switch to connect it to each cell or to the discharge circuit. This assists in determining the condition of the individual cells. There should be an ammeter in the discharge circuit, and preferably one in series with each cell. The scale of these latter ammeters should have the zero so located that the maximum discharge current may be read to the right and the maximum charging current to the left. As the accuracy required of these ammeters is not great, they may be small and inexpensive. Such a set of cells is also useful for supplying direct current to the series coils of wattmeters and watt-hour meters.

⁶⁴ The current through the potentiometer should be furnished by a storage cell used only for that purpose. This cell should be placed near the potentiometer, and should be well insulated. Such a mistake, for example, as using current from an end cell of a central-station battery for this purpose is liable to produce serious inaccuracies in the measurements, as well as to burn out parts of the apparatus.

For the voltage circuits of such instruments, and for direct-current voltmeters, it is desirable to have sets of smaller cells of 10 to 40 amperehours capacity, the number of cells depending on the maximum voltage to be supplied, and the amperehour capacity depending on how large a current will be drawn at one time, and what degree of steadiness of the voltage is required.

(g) **THE DEFLECTION POTENTIOMETER.**—The kind of potentiometer to be used will depend on the nature of the work to be done. Where the most refined precision is required, and accurate measurements must be made of very small electromotive forces, such as those of thermocouples, the potentiometer should be of the usual four-dial or five-dial form, or equivalent, and be used with a reflecting galvanometer. With this type of potentiometer it is difficult or impossible to make measurements on commercial circuits, and the equipment of storage cells just referred to can not be dispensed with. If the testing requires an accuracy not higher than one twenty-fifth of 1 per cent, and is limited to the testing of commercial electrical instruments, some advantages may be secured by using a deflection potentiometer. This potentiometer measures the larger part of the unknown current or voltage by the null principle, thus securing accuracy and reliability; the small margin of the result is read by the deflection of a pivoted moving-coil galvanometer, thus securing quickness of reading. These potentiometers, as designed at the Bureau of Standards, may be used on commercial circuits, as the changes in current or voltage are quickly followed by the galvanometer, which is designed to be just aperiodic, and takes up a new position without oscillation. Deflection potentiometers are semiportable, and when necessary may be carried about and used wherever required, as they require no special setting up and adjustment, as is necessary with reflecting galvanometers. If the circuit is fairly steady, one observer can read in succession the instrument under test and the deflection potentiometer. If the circuit is very unsteady, two observers may be required. The deflection potentiometer⁵⁵ was designed at this Bureau for its own use, and also with reference to the needs of instrument makers, central stations, and public-service commissions.

3. ALTERNATING- TO DIRECT-CURRENT TRANSFER INSTRUMENTS

All the preceding measurements can be referred, through standard resistances and standard cells, to the international electrical units. For

⁵⁵ H. B. Brooks, *Bulletin of the Bureau of Standards*, 8, p. 395, 1912; *Scientific Paper* 172.

the testing of alternating-current instruments it is necessary to provide, in addition to the potentiometer and its accessories, suitable transfer instruments; that is, instruments which can be calibrated on direct current and used without error (or with small and determinable error) on alternating current. Electrostatic and hot-wire instruments can be used for this purpose, and a recently introduced type employing the electromotive force of a thermojunction heated by the passage of the alternating current shows promise. The most suitable instruments for the purpose are, however, of the electrodynamic type, and for convenience of working they should usually be of the pivoted form, as suspension instruments, while indispensable for some purposes, are usually too troublesome and slow for commercial work. A portable electrodynamic voltmeter of good construction, with suitable multipliers, is a convenient transfer instrument for use in checking voltmeters of the moving-iron and the induction types. The inductance of the transfer voltmeter will not usually cause an appreciable error at any frequency used for lighting or power. If tests are to be made at higher frequencies, say 500 cycles, it is necessary to know the inductance of the voltmeter and to apply a correction for it if it is important to obtain the highest accuracy possible with the method.

For alternating voltages in excess of about 750 volts it is preferable to extend the range of the transfer voltmeter by using a voltage (potential) transformer instead of a multiplier. The ratio of such a transformer is varied by changing the secondary connected load, and hence it is advisable to have curves for the transformer showing its ratio from no load to full load for the frequencies to be used.

For the measurement of alternating-current power, well-made electrodynamic wattmeters should be used. In the best instruments of this type the inductance of the potential circuit will introduce no error of any practical consequence except at very low power factors. The effect of mutual inductance in good wattmeters is inappreciable at all ordinary frequencies. The effect of eddy currents in badly designed wattmeters is usually more serious than that of inductance in the potential circuit.

When the power of large currents is to be measured, it may be necessary or convenient to use a current transformer to extend the current range of the transfer instruments. At or near unity power factor, it is necessary to know only the ratio of transformation for the given secondary load and the frequency. With power factors appreciably below unity, it is also necessary to take into account the phase angle. (See p. 26.)

For the measurement of alternating currents of moderate value, say not over 200 amperes, electro-dynamometer ammeters are made which may be used as transfer instruments. For heavier currents, a 5-ampere ammeter of this type may be used in connection with a good current transformer of known ratio. In many cases it may be preferable to use a 5-ampere ammeter only, all higher ranges being measured with the help of current transformers, each of which may have several primary current ranges. It is not necessary to know the phase angle of the current transformers for this service. However, in using a current transformer for any purpose requiring accuracy, it should be remembered that the ratio and the phase angle vary not only with the secondary current and the frequency, but they also depend on the resistance and reactance of the instruments and connections in the secondary circuit.

To supply large currents for testing alternating-current ammeters, wattmeters, and watthour meters, transformers should be provided giving low secondary voltages, such as 2 and 4 or 4 and 8 volts, depending on the length and size of the current leads, the drop in each instrument and the number of instruments to be in circuit at once. The precision electro-dynamometer ammeters require several volts (the amount varying with the range) to pass full-load current through them. It is advisable to have the secondary voltage high enough to give a little margin over the anticipated requirements.

It is convenient to have indicating instruments of low cost and moderate accuracy in the test circuits, partly as a means of roughly checking results, and also to avoid overloading apparatus and circuits. Good moving-iron instruments are very useful for this purpose, as they give results correct to within a few per cent on direct current and the error certainly should not exceed 1 per cent on alternating current. They are of moderate cost, so that a good assortment may be provided without making a large outlay.

4. MEASUREMENT OF RESISTANCE AND FREQUENCY

A Wheatstone bridge should be provided, and should be kept set up with battery and galvanometer ready for use. Measurements should be made of the resistance of voltmeters, potential circuits of wattmeters, multipliers, volt boxes, etc., at the time these are received from the makers. These values should be recorded, and the resistance measurements should be repeated at intervals. Often a defective contact in a key or a loose wire

connection will be detected by a bridge measurement before the trouble becomes great enough to be apparent in service.

Defective contacts sometimes occur in the secondary windings of current transformers, particularly at the binding posts. As such defective contacts may seriously affect the performance of the transformer, a measurement of the resistance of the secondary winding should always be made before testing the transformer. It should be noted that this test should be made only with a Wheatstone bridge, or other device which requires only a very small current through the secondary winding. If the measurement of resistance were made by passing a direct current of several amperes through the secondary winding, the iron core would be magnetized, and the ratio and phase angle would be affected.

The Wheatstone bridge is not suited for very low resistance measurements, such as those of ammeter shunts. These may be determined by using a potentiometer, as described on page 53. If there is a considerable amount of low resistance measurement to be done, the use of a Kelvin double bridge is more convenient, as the current need not be kept as constant as for the potentiometer method for comparing resistances.

For the measurement of frequency, instruments of the vibrating-reed type are very useful. They are free from errors due to variation of voltage and wave form, which affect the indications of most other types of frequency meter, and are thus well suited to the laboratory, where it may be necessary to vary the wave form.



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DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR

OF THE

U.S.

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 21

PRECISION MEASUREMENTS OF RESISTANCE AND ELECTROMOTIVE FORCE

[1st Edition]

Issued March 1, 1910



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1. INTRODUCTION

This circular relates to those tests made by the Bureau involving only the precise measurement of resistance and electromotive force. It supersedes the corresponding section of Circular No. 6 (second edition, issued February 20, 1906). The regulations and fees herein given will be put into effect March 1, 1910. Regulations regarding other electrical tests are given in other numbers of the Bureau Circular, for which see page 27.

Since the organization of the Bureau of Standards there have been submitted for test resistance standards and resistance apparatus typifying the standard design and methods of construction adopted by the leading American and European manufacturers. The Bureau is equipped with such standard apparatus and also with special apparatus designed for work of the highest precision, further typifying the best methods of construction. The experience gained in its use and in the testing work has indicated the desirability of adopting specifications for all apparatus submitted for certification. In many cases a precision even greater than warranted by the best construction and far greater than that required in the work for which the apparatus was to be employed has been requested. These questions will be more fully discussed below. The experience thus gained has led to a classification of tests with respect to accuracy, based on the construction of the apparatus as well as on the work in which it is to be employed, and standard tests have been provided for most classes of apparatus. In many

cases two grades have been deemed adequate, one for the highest commercial accuracy and the other for all scientific work except special research in which the accuracy of the remaining data entering into the result justifies a still higher accuracy.

In such cases the Bureau will be glad to cooperate with investigators, not only in providing for tests of the highest precision, but also, on request, in furnishing any information at its disposal in reference to methods of measurement and the design and construction of special apparatus. The Bureau has extended a similar offer to manufacturers of electrical apparatus, with whom the most cordial relations have already been established.

2. THE INTERNATIONAL ELECTRICAL UNITS

The rapid development of the electrical industries, and the many improvements in the construction of electrical standards, electrical measuring apparatus, and methods of measurement, have together imposed increasing demands for accuracy in the units in terms of which electrical quantities are expressed.

The efforts which had been made in this direction previous to 1900 were fully set forth in a paper presented to the St. Louis International Electrical Congress in 1904.¹ This congress, recognizing the discrepancies in the laws of the countries represented, recommended that all matters relating to units of measurement be referred to an international commission which might, in the first instance, be appointed by those countries in which legislation had already been enacted, and the hope was further expressed that the commission might become a permanent one.

In accordance with the provision of the above resolution, an international conference was held in Berlin in 1905, at which England, France, Austria, Belgium, and the United States were represented. Certain recommendations were adopted, which it was agreed to propose for adoption to a congress in which all the leading countries were represented.

On behalf of England a call was therefore issued for an International Conference on Electrical Units and Standards, which met in London in October, 1908, and by which the following resolutions were adopted.

I. The conference agrees that as heretofore the magnitude of the fundamental electric units shall be determined on the electro-magnetic system of measurement with reference to the *centimeter* as the unit of length, the *gram* as the unit of mass, and the *second* as the unit of time.

These fundamental units are (1) the *ohm*, the unit of electric resistance which has the value of 1 000 000 000 in terms of the centimeter and second; (2) the *ampere*, the unit of electric current which has the value of one-tenth (0.1) in terms of the centimeter, gram, and second; (3) the *volt*, the unit of electromotive force which has the value 100 000 000 in terms of the centimeter, the gram, and the second; (4) the *watt*, the unit of power which has the value 10 000 000 in terms of the centimeter, the gramme, and the second.

II. As a system of units representing the above and sufficiently near to them to be adopted for the purpose of electrical measurements and as a basis for legislation, the conference recommends the adoption of the international ohm, the international ampere, and the international volt defined according to the following definitions:

III. The ohm is the first primary unit.

IV. The *international ohm* is defined as the resistance of a specified column of mercury.

V. The international ohm is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.300 centimeters.

To determine the resistance of a column of mercury in terms of the international ohm, the procedure to be followed shall be that set out in Specification I attached to these resolutions.

VI. The ampere is the second primary unit.

¹The So-called International Electrical Units, Reprint No. 3, Bulletin of the Bureau of Standards.

VII. The *international ampere* is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with the Specification II attached to these resolutions, deposits silver at the rate of 0.00111800 of a gram per second.

VIII. The *international volt* is the electrical pressure, which, when steadily applied to a conductor whose resistance is 1 international ohm, will produce a current of 1 international ampere.

IX. The *international watt* is the energy expended per second by an unvarying electric current of 1 international ampere under an electric pressure of 1 international volt.

The drafting of detailed final specifications was referred to a permanent commission and, pending its appointment, to an international scientific committee of 15, appointed by the president of the conference, Lord Rayleigh. In addition to the resolutions, the following recommendations were adopted.

In cases in which it is not desired to set up the standards provided in the resolutions the conference recommends the following as working methods for the realization of the international ohm, the ampere, and the volt:

1. *For the international ohm.*—The use of copies, constructed of suitable material and of suitable form and verified from time to time, of the international ohm, its multiples and submultiples.

2. *For the international ampere.*—(a) The measurement of current by the aid of a current balance standardized by comparison with a silver voltameter; or (b) The use of a Weston normal cell whose electromotive force has been determined in terms of the international ohm and international ampere, and of a resistance of known value in international ohms.

3. *For the international volt.*—(a) A comparison with the difference of electrical potential between the ends of a coil of resistance of known value in international ohms, when carrying a current of known value in international amperes; or (b) the use of a Weston normal cell whose electromotive force has been determined in terms of the international ohm and the international ampere.

The conference has considered the methods that should be recommended to the governments for securing uniform administration in relation to electrical units and standards, and expresses the opinion that the best method of securing uniformity for the future would be by the establishment of an international electrical laboratory with the duties of keeping and maintaining international electrical standards. This laboratory to be equipped entirely independently of any national laboratory.

1. The conference recommends that the various governments interested establish a permanent international commission for electrical standards.

2. Pending the appointment of the permanent international commission the conference recommends (1) that the president, Lord Rayleigh, nominate for appointment by the conference a scientific committee of 15 to advise as to the organization of the permanent commission, to formulate a plan for and to direct such work as may be necessary in connection with the maintenance of standards, fixing of values, intercomparison of standards, and to complete the work of the conference. Vacancies on the committee to be filled by cooptation.

3. That laboratories equipped with facilities for precise electrical measurements and investigations should be asked to cooperate with this committee and to carry out, if possible, such work as it may desire.

4. The committee should take the proper steps forthwith for establishing the permanent commission, and are empowered to arrange for the meeting of the next conference on electrical units and standards, and the time and place of such meeting should this action appear to them to be desirable.

A careful inspection of the definitions shows that two distinct systems of units are defined—the “practical units” of the absolute electro-magnetic system, and the concrete units of the international system, “representing the above, and sufficiently near to them to be adopted for the purpose of electrical measurements, and as a basis for legislation.” This is necessitated by the fact that at the present time the accuracy of the absolute measurements required to realize the units of the first system is considerably exceeded by the accuracy of reproduction of concrete standards from properly drawn specifications.

The *international ohm* and *ampere* were selected as primary units, but while general agreement was easily reached in regard to specifications for the construction of mercurial resistance standards, the disagreement of results of different investigators and even of the same investigator made it impossible to adopt specifications for the silver coulometer, as the cause or causes of the discrepancies, amounting to several hundredths per cent, were not known.

The adoption of a definite value for the electrochemical equivalent, 0.00111800 gram per second per unit current, still leaves both the international ampere and the international volt uncertain to the above extent. This, together with the high accuracy attainable in the reproduction of the Weston standard cell, has stood in the way of the acceptance of the value provisionally adopted by the London conference for the electromotive force of the cell, 1.0184 volts at 20° C. This difficulty would have been obviated by the selection of the volt instead of the ampere as the second fundamental unit, which would merely have required the adoption of a particular value for the Weston cell, as was advocated by the Bureau of Standards.

Arrangements have, however, been made by the international scientific committee to investigate the questions at issue by cooperative work, to be undertaken by representatives of the Physikalisch-Technische Reichsanstalt, the National Physical Laboratory, of England, the Laboratoire Central d'Électricité, and the Bureau of Standards, during the spring of 1910, in the laboratories of the Bureau of Standards, and it is hoped that, with the preliminary work in which the institutions cooperating are now engaged, agreement can be reached as to the details of the specifications and the numerical value to be adopted for the Weston normal cell. The international scientific committee has agreed to recommend that no further legislation be enacted until the cooperative work has been completed.

3. REFERENCE STANDARDS AND WORKING STANDARDS

A. RESISTANCE

Since the organization of the Bureau all resistance measurements have been referred to a considerable number of 1 ohm and 0.1 ohm precision standards of the Reichsanstalt design, verified from time to time at that institution. Beginning July 1, 1909, these were replaced by standards embodying the same principles of construction, but sealed to eliminate the influence of atmospheric humidity, as pointed out below.

The resistance material employed for standards is manganin, a copper-manganese-nickel alloy, one of a series first developed by Dr. Edward Weston, which is distinguished for the very small change in resistance exhibited with a change in its temperature, and for its small thermoelectromotive force against copper, as well as its superior constancy.

For standards of 0.1 ohm or more, silk covered manganin wire is employed, hard soldered to copper lugs, which in turn are soldered to copper terminals. The wire is wound in a single layer on a brass tube, first covered with shellacked silk gauze. After the wire is in place, the coil is shellacked and baked for at least ten hours at a temperature of 140° C.

For standards of 0.01 ohm or less, sheet manganin, hard soldered to the terminal lugs, is employed. The resistance material is in short lengths so that no further support is required. It is covered with a varnish to protect the alloy from the action of the atmosphere.

The standards of all denominations are provided with copper terminals amalgamated at the ends, located diametrically opposite each other, extending sufficiently beyond the case and above the center of gravity so that the standards can be hung in mercury cups, through which electrical connections are made. In addition, the standards of the lower denominations are

provided with potential terminals so that comparisons may be made by the various methods which eliminate the errors due to contact resistances.

The standards are designed for oil immersion, the oil serving to carry away the heat developed by the current passing through the coil, and facilitating the regulation and measurement of the temperature.

The heat developed increases the temperature of the resistance material above that of the bath in which it is immersed approximately 1°C per watt for 0.1 ohm and 1 ohm standards of the above design. In air, the increase in temperature is at least five times larger. The temperature increase for standards below 0.1 ohm is generally not over 0.25° per watt in oil, depending upon the surface area of the resistance material.

The baking referred to above leaves the standard free from alcohol and moisture. On exposure to atmosphere or oil at ordinary temperatures, the shellac used in insulating and protecting the winding absorbs moisture until an equilibrium condition is established with the moisture content of the atmosphere or oil. Any changes in the humidity of the atmosphere or oil will be followed, though slowly, by corresponding changes in moisture content of the shellac. As the humidity of the atmosphere changes with the seasons, the amount of moisture in the shellac will also vary with the seasons unless some means, such as hermetical sealing, is provided to eliminate the effect. Changes in the amount of moisture in the shellac change its volume, and changes in the volume alter the tension and dimensions of the wire and consequently the electrical resistance of the standard. The absorption of moisture by the shellac thus accounts for the seasonal changes observed and also in part for the increase in the resistance of comparatively new standards.

The 0.1 and 1 ohm standards are usually more constant than those of other denominations. Here the wire is of such a size that the expansion of the shellac can produce but a slight stretching, and the surface action is less than with standards in which wires of smaller diameter or thin sheets are employed. Standards of these denominations seldom show a change of more than 0.003 per cent per year after the first year, and the seasonal changes are small, usually not exceeding 0.002 per cent for 1 ohm standards under ordinary conditions.

Sealed standards.—The constancy of manganin resistance standards may be very materially increased by sealing them in cases containing a good grade of oil free from moisture. This matter is fully discussed in Reprints Nos. 73 and 107 from the Bulletin of the Bureau of Standards, copies of which will be sent, on request, to those interested. The sealed standards of the Bureau, which have been developed as a result of this investigation, embody the essential principles of the Reichsanstalt design, differing only in the dimensions and in the case being sealed and filled with carefully dried, high-grade petroleum. The cases are approximately 4 cm in diameter and 12 cm high, and the distance between the centers of the terminals is 7.7 cm, thus reducing the dimensions of the comparing bath. In measurements of the very highest precision, made in a regulated oil bath, the time required to reach temperature equilibrium is considerably reduced by the smaller dimensions. In most cases, no oil bath is required.

Since July 1, 1909, the reference standards of the Bureau have consisted of at least five 1-ohm coils of the sealed type. These are compared with each other and with the standards which have heretofore been employed to

detect any relative changes. The construction of primary mercurial resistance standards is well under way, and when completed the results will be compared with those of other national laboratories. The plan of cooperation outlined at the London International Electrical Conference of 1908 will, it is hoped, soon be put into effect so that the unit of resistance of all the institutions will be made identical by giving proper weight to the results obtained by each. Until then the values adopted for the reference standards will be expressed as heretofore in terms of the primary mercurial standards of the Reichsanstalt.

Working standards.—Decimal multiples and submultiples of the international ohm are represented by at least two working standards of each denomination, referred from time to time to the reference standards. The multiples of the unit are of the sealed type, and the submultiples of the Reichsanstalt design. The latter, as also the units, are provided with potential terminals.

B. ELECTROMOTIVE FORCE

Standard cells.—The standards of electromotive force of the Bureau consist of a considerable number of Weston normal cells constructed in accordance with the preliminary specifications described in Reprint No. 67 from the Bulletin of the Bureau of Standards. These are maintained at 25° C in automatically regulated petroleum baths practically all the time, except during the summer months, when auxiliary cooling, which occasionally fails, must be employed.

The mean value taken for the reference cells is based on the value adopted at Chicago in 1893 for the Clark cell, set up in accordance with the specifications adopted shortly after the Chicago congress, namely, 1.434 volts at 15° C. Such cells are found to have a value higher by 0.0003 volt than Clark cells set up with specially prepared or treated mercurous sulphate. Assuming the temperature formula found at the Physikalisch-Technische Reichsanstalt, the value of the Clark cell set up with properly prepared mercurous sulphate on the same basis was taken by the Bureau as 1.42110 international volt at 25°.

On this basis, the mean value for the Weston normal cell has been found to be 1.01890 volt at 25°, or 1.01913 at 20°. The change in electromotive force with temperature is given by the formula

$$E_t = E_{25} - 0.0000406 (t - 20^\circ) - 0.00000095 (t - 20^\circ)^2 + 0.00000001 (t - 20^\circ)^3$$

adopted by the London International Electrical Conference of 1908.

The above value of the Weston normal cell is identical within the limits of accuracy of reproduction with that heretofore employed by the Bureau of Standards, and will be retained until a satisfactory agreement has been reached by which strict international uniformity will be secured.

The value for the Weston normal cell used in England prior to the International Electrical Conference of 1908 was 1.0193, at 20° C. Since January 1, 1909, the value used in England has been 1.0184 at 20° C. The value used in Germany is 1.0186 at 20° C for the older Weston cells, or 1.0185 for those set up with mercurous sulphate prepared according to methods recently developed.

4. ACCURACY REQUIRED FOR VARIOUS CLASSES OF WORK

The increased application of electrical methods to many classes of physical measurements, and the more rigorous specifications for certain classes of commercial electrical apparatus, have created a demand for more precise electrical measurements. As the sensibility is, however, usually high, the measurements are frequently being made to a precision which is not justified by the needs of the work or by the apparatus used. It therefore seems desirable to point out some of the more obvious limitations.

The users of apparatus for the measurement of resistance and electromotive force may be grouped roughly into two classes—(1) those engaged in university work and in other research and testing laboratories, or in the manufacture of standards and measuring apparatus, and (2) those engaged in commercial work. Among the latter are the manufacturers of dynamo-electric machinery, power supply, telegraph and telephone companies, refiners of copper and aluminum, wire manufacturers, etc.

In some classes of work, particularly in connection with laboratory instruction in our technical schools and colleges, where the aim is to familiarize the student with the methods of electrical measurement and impress him with the precision attainable, *relative accuracy* is obviously the principal requirement, as, for example, in the comparison of two nearly equal resistances. This is the sole requirement when the ratio of two quantities is determined from the ratio of two resistances, as, for example, in the comparison of electromotive forces or resistances by the potentiometer. For absolute accuracy the values of the various quantities entering into the result must be known in terms of the international electrical units, except where the ratio of two quantities of the same kind is involved, as in the ratio coils of a Wheatstone bridge and in resistance thermometry. As pointed out in this circular, the fundamental international electrical units, the ohm and ampere, are not at present fixed to better than 0.002 and 0.01 per cent, respectively, while their relation to the corresponding absolute units is even more uncertain.

The accuracy of reproduction of the standard cell being approximately the same as that of the mercury ohm, the limit to the accuracy to which results can be expressed in terms of these concrete standards, assigning a particular value for the standard cell, may be taken as 0.002 per cent.

In precision work an accuracy of 0.01 per cent is to be considered fully adequate. To secure even this precision the work must be done with well designed apparatus suitable for the particular work. Corrections must be applied for change of values or indications with temperature, and in addition the apparatus must be checked from time to time with reliable reference standards. The changes between comparisons are frequently large and are very often overlooked, the agreement between repeated measurements of the same quantity being taken as a measure of the *absolute accuracy* of the result.

The Grade A tests listed below are provided for this class of work, certifications being made to a maximum accuracy of 0.005 per cent for resistance standards and 0.01 per cent for other resistance apparatus complying with the specifications given below. However, in cases where only relative values are required, these will be given to a precision not greater than 0.001 per cent, the limit being determined by the construction and design of the apparatus. It is recommended that such apparatus be designed so as to

make possible a complete intercalibration without the aid of much accessory apparatus, as, for example, in some decade rheostats and potentiometers where the separate coils of each decade can be intercompared and the decades intercompared by a comparison of the ten coils of one decade with the first coil of the next higher decade. Apparatus will not be tested to a higher accuracy, except in special cases noted above, page 4.

In commercial work an accuracy greater than 0.1 per cent is seldom sought and less frequently attained on account of the unfavorable conditions under which the measurements must generally be made; for example, temperature uncertainty, fluctuation of the quantity to be measured, limitations to the accuracy of deflection instruments, etc. Apparatus employed for this class of work should, therefore, be tested to an accuracy sufficient to give the result to within 0.1 per cent under favorable conditions and when the apparatus is suitable for the purpose for which it is employed. This requirement is fully met by the Grade B tests listed below, the limit of accuracy being fixed at 0.025 per cent. Resistance apparatus adjusted to give this accuracy can be obtained from a number of makers, thus rendering unnecessary the application of corrections. Even for this class of work the purchase of high-grade apparatus is recommended, since its increased cost is more than offset by its greater reliability as well as the time saved in its use. Provision has been made by the Bureau of Standards for checking such apparatus, at a reduced fee, to determine whether the specifications have been complied with; in this case the corrections found are not given. However, in view of large changes frequently observed, particularly in coils of 1000 ohms and above, even the highest grade apparatus should be checked from time to time. In many cases other resistance apparatus is available, and in some cases the coils may be intercompared, thus checking any relative changes. In the absence of adequate checks the apparatus should be submitted periodically to some standardizing laboratory.

5. CLASSIFICATION OF TESTS

A. PRECISION RESISTANCE STANDARDS—ACCURACY, GRADE A

See Fee Schedule 71, p. 27

Standards submitted for certification as precision standards must satisfy the following requirements:

(1) Standards must be adjusted to within 0.1 per cent of the following nominal values in international ohms: 1, 2, 3, 4, 5, and their decimal multiples up to and including 100 000 ohms, together with the decimal sub-multiples of the unit, down to and including 0.0001 ohm.

(2) Standards must be of approved design and construction and must embody the main features of the Reichsanstalt type, already described, and generally adopted by the leading manufacturers.

(3) The resistance material must be distinguished by its constancy. Its change in resistance with temperature must not exceed 30 parts per million per degree centigrade at 25° C, and its thermoelectromotive force against copper must be small.

(4) To facilitate the measurement and control of the temperature, the standard must be so designed that it can be compared in an oil bath.

(5) In coils of 1 ohm and above, the resistance material should be in the form of wire of suitable size closely wound on a hollow supporting cylin-

der, and should cover a surface of at least 40 square centimeters area. In standards below 0.1 ohm sheet metal is usually employed. The surface must be sufficiently large, so that the heat developed by the test current does not cause a rise in temperature of the resistance material above that of the oil bath in which it is used of more than 0.25°C per watt.

(6) Standards of 0.1 ohm and below must be provided with potential terminals, so that all connecting resistances can be eliminated. This construction is also recommended for 1-ohm coils. The resistance in each potential lead should not exceed 0.001 ohm, to facilitate measurements by the Kelvin double-bridge method.

(7) If the resistance material is affected by atmospheric influences, it must be covered with a suitable protecting varnish.

(8) The standard must be provided with suitable copper terminals, projecting at least 1.5 cm beyond the edge of the case, for making electrical connections and for supporting it in mercury cups.

(9) Standards having a resistance of over 20 000 ohms must be subdivided and have not over 20 000 ohms per section.

(10) New standards must be accompanied by a statement concerning the resistance material used and the date and process of aging.

Standards submitted for certification will be compared with or referred to at least two of the working standards of the Bureau. The measurements will be made in an oil bath and by the Wheatstone bridge or by the Kelvin double-bridge method.

The values will generally be given to 0.001 per cent, but will in no case be certified to an accuracy greater than 0.005 per cent. This limit is determined by (a) the accuracy of reproduction of the international ohm from its definition, together with its comparison with wire copies estimated at about 0.002 per cent; (b) the accuracy of the evaluation of the multiples and submultiples from the unit estimated at 0.0002 per cent per step of 10; (c) changes in the Bureau reference standards between evaluations estimated to be not more than 0.002 per cent.

When the resistance material is manganin, the value can be expressed by the following equation:

$$R = N\{1 + a + b(t - 25) + c(t - 25)^2\}$$

in which R denotes the resistance, t the temperature, N the nominal value of the standard, a the correction in parts of the whole at 25°C , and b and c the constants of the temperature formula.

For manganin the value of b is usually between -0.000010 and $+0.000030$, and the corresponding value for c is usually between -0.0000003 and -0.0000005 . It will thus be seen that the changes in temperature which occur under working conditions in the laboratory, say 20 to 35°C , cause changes in resistance from the 25°C value of usually not over 0.02 per cent, and need be considered only when a higher accuracy is sought.

Since it often happens that measurements are desired to a higher relative accuracy, it is recommended that the temperature resistance equation of all precision standards be determined. For this purpose, measurements at three temperatures suffice. These will generally be made at 20 , 25 , and 30°C to a relative accuracy better than 0.005 per cent. In this case the formula will give the temperature correction between 20° and 30° to within ± 0.0005 per cent, or at any temperature to within $\pm 0.0000002(t - 25)^2$.

In the case of standards of the higher and lower denominations, which are seldom used in measurements requiring a relative precision much better than 0.005 per cent, a determination of the mean temperature coefficient from measurements at two temperatures will suffice. When the resistance material is known to be manganin, a closer approximation may be obtained by assuming c , in the above equation, to have its mean value -0.0000004 . If the measurements are made at temperatures differing by 10°C , an error of 50 per cent in the assumed value of c introduces, within these limits, a maximum error of only 0.002 per cent.

As new standards often change more rapidly during the first few months than later, it is recommended that when such standards are submitted for test they be left in the Bureau at least a month after the completion of test outlined above, and that an additional measurement then be made at 25°C .

For standards of which the resistance-temperature formula has previously been determined in any of the national laboratories, it is recommended that measurements be made at 25°C only, since experience shows that the change in resistance with a change in temperature is the same at different times within the limits of measurement. There is, therefore, no object in making additional measurements at other temperatures.

In cases where the standard is to be employed for current measurement or otherwise unduly loaded it is desirable to know the effective difference in temperature between the resistance material and the oil bath. An additional measurement with a larger test current or higher voltage is generally sufficient for determining this relation for standards of which the resistance temperature equation is known, except when strains are produced by differential thermal expansion, by which appreciable changes in the resistance may be caused.

B. PRECISION RESISTANCE STANDARDS—ACCURACY, GRADE B

See Fee Schedule 72, p. 28

Standards submitted for certification under this schedule must be of approved design, and it is recommended that they should in general satisfy the requirements laid down for precision standards as given above. Apparatus which does not quite meet the requirements for a test under Schedule 71 may be submitted for certification under this schedule.

The measurements will be made at a temperature of 25°C only, and the results certified to an accuracy not greater than 0.025 per cent. It is not necessary to make measurements at other temperatures, since the resistance should not vary by more than the limit set with ordinary temperature changes.

C. RESISTANCE STANDARDS FOR CURRENT MEASUREMENT—ACCURACY, GRADE A

See Fee Schedule 73, p. 28

Standards submitted for certification under this schedule must be of approved design and construction, and must satisfy the following requirements:

(1) They must be decimal submultiples of 1, 2, 3, 4, or 5 ohms, between 0.0001 and 1 ohm, both inclusive.

(2) They must be adjusted within 0.2 per cent of their nominal values.

(3) The resistance material must be distinguished by constancy of its

resistance, small thermoelectromotive force against copper, and small change in its resistance with a change in temperature. This change per degree centigrade must not exceed 30 parts per million at 25°C . If it is easily oxidized, it must have a covering to protect it against the action of the atmosphere or moisture dissolved in oil.

(4) Standards below 1 ohm must be provided with separate current and potential terminals. The potential connections must be so located that any changes in the current distribution in the current terminals will introduce no appreciable errors. The resistance of each potential connection should not exceed 0.001 ohm, and the current connections should have a very low resistance and sufficient contact surface to keep the local rise in temperature within reasonable limits.

(5) The standards must be provided with a suitable tank or containing case, to be filled with oil when in use.

In standards of this type, when used with the rated full-load current, the temperature of the resistance material is generally considerably above that of the oil. The difference depends upon the area exposed to the oil and the circulation of the latter.

Standards received for test under this schedule will be compared with certain reference standards of the Bureau, and the value obtained certified to an accuracy of 0.01 per cent.

It is recommended that the test consist of three measurements—(a) one made with the bath at room temperature and with a small test current, to obtain the resistance, (b) a second measurement with the bath about 10°C above room temperature, to determine the effect of temperature, and (c) a measurement with the rated full-load current, to determine the effect of the test current which is due to the heating of the resistance material above the temperature of the bath. The three measurements give the data from which an equation may be derived giving the resistance with the bath at different temperatures and with any test current up to full load.

When the oil tank is provided with means for regulating the temperature by water circulation, measurements may be made at any desired temperature between 15° and 35°C . Where a suitable means for cooling the oil is not provided, measurement, in general, will not be made below the room temperature.

D. RESISTANCE STANDARDS FOR CURRENT MEASUREMENT—ACCURACY, GRADE B

See Fee Schedule 74, p. 28

Standards submitted for certification under this schedule must satisfy the following requirements:

(1) They must be of approved design and construction, and in general satisfy the requirements for certification under Schedule 73, except that they need not be designed for oil immersion.

(2) The thermoelectromotive force of the resistance material against copper must not exceed 3 microvolts per degree centigrade.

(3) The standard must be so designed that with its rated full-load current the rise in temperature above that of the room does not exceed 50°C , and the change in resistance from no load to full load must not exceed 0.1 per cent.

When the standard is to be used with different loads, it is recommended that a test be made with a small current and, also, with the rated full-load

current. In some cases, an additional test at half load (0.5 the rated watts, or 0.7 the rated full-load current), is desirable, since the change in resistance with the load is not strictly proportional to the load.

When the resistance material is in short lengths, considerable heat is conducted away from the standard by the connecting lugs. In such cases, it is suggested that the lugs be sent with the standard so that the test may be made more nearly under the conditions of service, which should be stated fully in the application for the test.

Standards received for test under this schedule will be compared with reference standards of the Bureau and the values found certified to an accuracy of 0.025 per cent.

The temperature of the room in which the tests are made will be given.

E. PRECISION RESISTANCE APPARATUS—ACCURACY, GRADE A

See Fee Schedule 75, p. 29

Precision resistance apparatus consists usually of a number of resistance coils mounted from a hard-rubber support and connected to metal terminal blocks by means of which, with plugs or switches, certain combinations of the coils are effected. The requirements of such apparatus are determined by the nature and range of measurements to be made, the speed of working, and precision desired. In this discussion, only apparatus capable of giving an accuracy of 0.01 per cent will be considered. The reliability depends on the material and construction of the resistance coils, the quality of the insulation, and the contact resistances introduced by the plugs or switches.

The construction of the coils should in general be similar to that described above for precision standards. Single-layer windings on metal cylinders give the most satisfactory results. Wood spools should not be used, particularly for the coils of higher resistance, as they may absorb moisture, thus producing strains in the wire.

The changes of resistance of shellacked coils, due to atmospheric humidity, may be largely eliminated by giving them a thin coat of paraffin; this practice is highly recommended. However, the coils must not be heavily embedded in paraffin or other material, which unduly retards attainment of temperature equilibrium.

Manganin has been found by experience to be the most suitable resistance material, and is now almost exclusively employed in precision apparatus.

The terminal blocks should be firmly fastened to the hard-rubber top; this is to be particularly observed when the series plug arrangement is used, so that the removal of a plug may disturb the fit of adjacent plugs as little as possible. In order to secure a permanently high insulation, a space should always be left at the base of the blocks, by undercutting them or otherwise, sufficient to permit cleaning the surface of the hard rubber; the hard rubber should also be protected from the action of direct sunlight.

Each terminal block should be provided with an auxiliary means for making direct electrical connection to it, either a screw or a tapered hole with a traveling plug. Such a connection is often found to be convenient in the calibration of the apparatus, and sometimes in its use. For similar reasons, such a connection should be provided for all the main branch points of an apparatus.

The desired combinations of the coils are usually made by plugs or switches. A few words of caution are necessary in regard to their use and care. When plugs are used a good fit between plug and hole is essential. Both the plugs and the holes should be cleaned frequently; the surfaces should be in such condition that good contact can be made without excessive pressure, which may disturb the fit of adjacent plugs. The plugs should not be inserted with a screw motion in one direction, and be withdrawn with an opposite motion, as this may wear grooves in the holes and produce high contact resistance. When a plug is removed it should always be ascertained that adjacent plugs have not been disturbed. The importance of frequent cleaning is just as great in the case of switch contacts. The magnitude and constancy of the contact resistance depend also on the design of the contact. A plug contact of the best design and construction has a resistance of about 0.00006 ohm, and is constant when clean to 0.00002 ohm. The best switch contact has a resistance of about 0.0002 ohm, and is constant to better than 0.0001 ohm. These figures are for the best conditions, being considerably better than ordinary practice. Either type of contact, when dirty or grooved, is not reliable to 0.01 ohm, and if not cleaned often enough a film of oxide forms, which makes them still worse. Switch dial apparatus is more convenient and rapid in operation than plug apparatus, and is therefore to be preferred for most purposes.

The number of contact resistances in series should be kept small. If this can not be done, the total resistance used should, if possible, be chosen large enough so that the contact resistances are negligible in comparison with it.

The coils of low value in resistance apparatus are often adjusted much closer than necessary. This is due to the practice of specifying a certain percentage accuracy of adjustment for the coils of an apparatus without recognition of the fact that the desired precision of measurement does not require the same percentage accuracy in all the coils. Now, it is evident that coils used in series with a number of plugs or switches can not be relied upon to better than 0.001 ohm. Furthermore, in the use of resistance apparatus, the quantity to be measured is generally determined by two or more factors, at least one of which is given by a resistance adjustable in equal steps, e. g., the rheostat arm of a Wheatstone bridge. For nearly all purposes, steps of 0.1 ohm have been found sufficiently small, and apparatus with coils of smaller denomination is rarely found. The magnitude of the smallest step and the total resistance with which it is in series determine the percentage accuracy of the reading. A closer determination is sometimes made by interpolation to 0.1 or, rarely, 0.01 of a step. It is therefore evident that an accuracy exceeding 0.0005 ohm in the adjustment or calibration of the coils of lower denomination is practically superfluous. For the coils above 5 ohms, the limit is fixed by the percentage accuracy of adjustment.

Apparatus submitted for certification must satisfy the following requirements:

(1) In general, the apparatus must be capable of giving an accuracy in service of 0.01 per cent.

(2) The resistances must be adjusted to 0.1 per cent of their nominal values, except in the case of coils below 1 ohm, as noted above. While this accuracy will admit to certification under this schedule, closer adjustment is highly desirable since most users prefer to dispense with corrections.

(3) The plugs or switches must be in good condition. The variation in resistance must not exceed 0.0001 ohm for each plug and 0.0002 ohm for each switch.

(4) The insulation must be good throughout, and must be in good condition.

(5) New apparatus submitted by the makers must be accompanied by a statement concerning the resistance material used, and the date and process of aging.

To obtain 0.01 per cent accuracy the apparatus must be kept in first-class condition and the resistances checked from time to time. Since appreciable changes in resistance occur during the first year or two, new apparatus should receive special attention. Some apparatus made by the best makers has been found at the Bureau to show a permanent increase of over 0.1 per cent in resistance. This effect, like that of moisture (see above), is greater in the case of the coils of higher resistance.

The request for a test should contain a statement of the purpose and conditions of use of the apparatus. The party submitting the apparatus may be required to show that a calibration to the precision of this schedule is required in the work for which the apparatus is used. The measurements will be made at room temperature. If measurements at other temperatures, or a higher accuracy than 0.01 per cent, are required, the test will be regarded as special (see p. 24).

(a) BRIDGES, RHEOSTATS, AND SIMILAR APPARATUS

For the measurement of resistances, the Wheatstone bridge and modifications are usually employed. The bridge may have continuously variable ratio arms and one or more fixed comparison resistances, or it may have fixed ratio arms and a variable rheostat as the comparison resistance. In the measurement of resistances less than 1 ohm, the Kelvin double bridge should be used;² the apparatus provided for this work is usually a double set of similar ratio arms, together with a low resistance standard. The rheostat arm of a Wheatstone bridge, and rheostats in general, may consist of a simple series of coils short-circuited by plugs, or of any one of several decade arrangements. If the series plug arrangement is used, the cautions mentioned above should be observed. The decade arrangements consist of groups of equal decimal steps. They are easier and quicker to manipulate and involve fewer contact resistances. They are adaptable either to plug or switch connections.

The ratio arms of a Wheatstone bridge should be reversible. The connecting resistance to the branch points of the bridge (galvanometer or battery connection points) must be low, and should not exceed 0.0002 ohm if ratio coils as small as 1 ohm be used. There should be not more than two contact resistances in a ratio arm. In bridges of older design, the ratio coils are in series, and are thus more subject to plug troubles. For facility in calibration, auxiliary potential connections should be provided to the branch points, or terminal points of ratio arms. Connecting resistances in the bridge should always be made low, and the galvanometer and battery should be introduced at such points that the connecting resistance is in series with the rheostat arm rather than the ratio arms or the resistance

² For a treatment of the theory and practice of this method, see Jaeger, Lindeck, and Dieselselhorst, *Zeitschrift für Instrumentenkunde*, 28, pp. 33 and 65; 1903.

under measurement. In the use of a bridge, the ratio arms should be chosen which will give a large setting of the rheostat arm, in order to obtain a high percentage accuracy of reading, provided that such a choice is consistent with sensibility.

A slide wire is often used in rheostats and bridges. When the resistance of the contact is in series with the other resistances, and its constancy must be relied upon, trouble arises sooner or later; this construction is seldom to be recommended. Where the sliding contact functions otherwise, as when its resistance enters only in the battery or galvanometer circuit, very satisfactory results may be obtained. In some cases the wire and contact should be oil immersed. It should be ascertained that negligible or constant resistances are introduced at the junctions of the ends of the slide wire with the rest of the apparatus.

A regular test will include the determination of resistance of each coil and the magnitude and constancy of zero and connecting resistances (each charged for as one coil) of each arm or separate portion. If there is a slide wire, its total resistance will be determined and charged for as one coil, and it will be calibrated at 10 points, or every half turn if it is wound on a cylinder. If the plug or switch contacts are in such condition that they must be cleaned in order that the accuracy of this schedule may be attained, an extra fee will be charged, as per table of fees.

The certificate will ordinarily give the corrections in international ohms. Corrections to rheostat coils will generally be given in terms of the "substitution equivalent," or the resistance added when the coil is introduced into the circuit in the ordinary way. Thus, in the case of a series plug connection, the substitution equivalent is not the resistance of the coil, but that of the coil minus that of the plug. In cases where the number of contacts in series is not variable, as in the decade arrangements, the substitution equivalent is identical with the coil resistance. In any case, the true resistance is found by adding to the rheostat setting the zero resistance, which includes the sum of the contact resistances. The corrections for ratio coils will include the connecting resistances in series with them.

The corrections to the coils will ordinarily be certified to an accuracy of 0.01 per cent, except the resistances below 5 ohms. The latter will be certified to 0.0005 ohm only, or to a lower accuracy if the number or condition of the contacts are unfavorable. Ratio coils will be certified to 0.005 per cent, except those below 10 ohms. Where the construction admits, the accuracy of determination of the points on a slide wire will be 0.2 of its smallest division.

It should be remembered that resistances are often not constant to 0.01 per cent, so that the certificate can not guarantee that accuracy in the use of apparatus. We can do no more than certify to the accuracy of our determination at the particular time of test.

(b) POTENTIOMETERS AND VOLT BOXES

Serving the widest variety of uses, the potentiometer is a most accurate and convenient electrical measuring apparatus. It is essentially an instrument for comparing differences of potential. This is effected by balancing them against the difference of potential in a portion of the potentiometer circuit, through which a constant current is maintained. The instrument

must therefore be so constructed that the potential difference between two terminals can be varied continuously, or in sufficiently small steps, without changing the total resistance in the potentiometer circuit. In the measurement of potential differences, an unknown and a standard are successively balanced; and, provided only that the current in the instrument remains the same for the two operations, the unknown potential difference is given in terms of the standard by the ratio of the potentiometer settings. It is thus apparent that the corresponding resistances need be known only relatively. The accuracy of measurement, accordingly, depends chiefly upon the relative accuracy of the potentiometer resistances, the accuracy of the cell used as standard, and the sensitiveness of the galvanometer employed to indicate a balance. These three requirements are so well met in practice that with a potentiometer whose calibration is carefully and frequently checked, an accuracy of 0.01 per cent is very easily attainable.

Besides its accuracy, the potentiometer has the advantage of convenience. The resistances are divided into groups or decades of equal steps. The potential drop in one step of a decade equals that in ten steps of the next lower decade. The successive dial readings thus give the digits of the setting. A slide wire may take the place of several of the dials. It is only necessary to adjust the current to such a value that the standard cell is balanced across a portion of the resistance indicating its electromotive force, when the readings of the instrument will give the potential differences subsequently measured, without calculation. In addition to the direct measurement of voltage, the potentiometer furnishes a means for the precise measurement of current and of resistance when used in connection with resistance standards. By using resistance standards of decimal values the advantages of direct reading are retained for current measurements, only the insertion of the decimal point having to be considered. For flexibility, accuracy, and convenience the potentiometer is thus seen to be an admirable instrument for the measurement of the three fundamental electrical quantities. By combining measurements of two of these quantities we have also a measure of power.

The numerous types differ in the method of dividing the potential drop into decimal steps. One of the simplest forms is a series of equal coils with a slide wire having decimal subdivisions and a resistance equal to one coil. A switch makes contact with the terminal of any one of the series coils, and there is also means for making contact at any point of the slide wire. Practical considerations of construction limit the values of the resistances that may be employed when the series slide wire is used to 20 to 100 ohms per volt on the normal range. The Crompton and the Leeds & Northrup Type K potentiometers are of this form.

When high resistances, of the order of 10 000 ohms per volt, are employed, various methods are employed to make the potentiometer settings. In one type there are several dials of equal coils in series, whose steps are multiples of 10. The terminals to which the unknown potential difference is applied connect to the switches of the two end dials. Changing the resistance on the intermediate dials varies the drop between these terminals, the current being maintained constant by simultaneously changing the resistance in the battery circuit a corresponding amount. This double operation is effected by the use of double dials. The Otto Wolff potentiometer is of this type. In

another type the steps of the main dial are subdivided by means of a second series of coils, which can be moved so as to shunt any one, or, in some types, any group of two or more of the steps of the main dial. Examples of this type are the Siemens & Halske and the Leeds & Northrup Standard potentiometers. A recently developed type combines the potentiometer with the deflection principle. The greater part of the unknown potential difference is balanced in the ordinary manner, and the small unbalanced remainder is indicated on a deflection instrument. This method has the advantage of speed, and an accuracy of 0.02 per cent is attainable.

The types of potentiometer differ, also, in the method of balancing the standard cell. It may be introduced at the same points as the unknown potential differences, or special connections may be provided for it. The latter arrangement is the more convenient, as it is unnecessary to disturb the setting of the instrument. This is of importance, for the constancy of the current is the fundamental assumption of the potentiometer, and should be frequently checked. Usually a single pair of tap-in points for the standard cell is not sufficient. Preferably the resistance across which the cell is balanced should be variable, inasmuch as the cells used as standards do not all have the same electromotive force, and, further, because their variation with temperature may have to be considered.³

A few words may be said regarding the relative advantages of high and low resistance potentiometers. The chief advantage of the low resistance is in sensibility, which increases as the resistance is reduced. In the low-resistance instrument, the effect of poor insulation and possible leakage between parts is less important than in the case of high resistance. The change of the resistances with time and their variation with atmospheric humidity are also less in the case of low resistances. (See general discussion under "Resistance standards," p. 7.) The low-resistance potentiometer has, however, the disadvantage of using a larger current, which is somewhat more difficult to maintain constant. The slide wire types often have additional minor difficulties, which can, however, be overcome by proper construction.

The range of the ordinary potentiometer is 1.5 to 1.8 volts, 0.1 volt for each step of the first or main dial. The setting is usually readable directly to 0.00001 volt. For measuring very small potential differences the range of some potentiometers may be reduced. The reduction is usually to 0.1 or 0.01 of the normal range, and is accomplished by inserting series resistance or a combination of shunt and series resistance with the main circuit. The

³ Full descriptions of the various types may be found in the pamphlets of instrument makers. Short treatments of the subject are given in various text-books. For careful treatments of theory and types, see—

K. Feussner; *Zeitschrift für Instrumentenkunde*, 10, p. 113; 1890.
 O. Wolf; *Zeitschrift für Instrumentenkunde*, 21, p. 227; 1901, and 28, p. 301; 1903.
 A. Raps; *Elektrotechnische Zeitschrift*, 15, p. 215; 1895, and 16, p. 507; 1895.
 R. Franke; *Elektrotechnische Zeitschrift*, 24, p. 978; 1903.
 J. A. Harker; *Philosophical Magazine*, 6, p. 41; 1903.
 R. A. Leffeldt; *Philosophical Magazine*, 5, p. 668; 1903.
 H. Hausrath; *Annalen der Physik*, 17, p. 735; 1905, and *Zeitschrift für Instrumentenkunde*, 25, p. 353; 1905.
 H. Diesselhorst; *Zeitschrift für Instrumentenkunde*, 26, pp. 173 and 297; 1906, and 28, pp. 1 and 38; 1908.
 W. P. White; *Zeitschrift für Instrumentenkunde*, 27, p. 210; 1907, and *Physical Review*, 25, p. 334; 1907.
 H. B. Brooks; *Bulletin of Bureau of Standards*, 2, p. 225; 1906, and 4, p. 275; 1908.

percentage precision of reading is thereby increased inversely as the reduction factor, unless limited by galvanometer sensibility. Special potentiometers for the measurement of low potential differences are also constructed, which are designed for the prevention of errors due to thermal electromotive forces and variable contact resistances in the potentiometer circuit. Such an instrument should be of low resistance to secure the highest sensibility.

Volt boxes.—When a potentiometer is used to measure higher voltages than 1.5 volts, a “multiplier,” or volt box, is ordinarily used. A volt box is a series of resistance coils to the terminals of which is connected the unknown voltage and across a known fraction of which the drop is measured. The ratio of the total resistance to this fraction is the multiplying factor of the box. The construction is generally such as to give two or more factors. In the design of volt boxes, the need of specially good insulation must be regarded; and great care is necessary in use to prevent the high voltage under measurement from leaking to the potentiometer. The terminals of the volt box must be well separated and well insulated. The resistance should be divided into a number of coils in series, both for insulation and for dissipation of heat. The lower the resistance used the greater will be the heat developed. However, a high resistance reduces the sensibility, and is moreover less constant. The use of wooden spools and the winding of more than one layer on a spool are alike prejudicial to heat dissipation and to constancy of resistance. The resistance used should be between 100 and 300 ohms per volt.

The testing of potentiometers and volt boxes involves somewhat different measurements than are required for bridges and rheostats. A regular test of a potentiometer will include as many of the following measurements as are required to test the instrument completely:

(a) Comparison of the coils of the main dial or dials to an accuracy of one-half the smallest step or division of the instrument, except that such accuracy shall be not better than 0.01 per cent of one of the steps of the first main dial. Each zero or connecting resistance in series with the coils, which must be measured, will be charged for as one coil.

(b) Checking of the auxiliary compensating coils to ascertain whether their compensation is within the above accuracy.

(c) Determination of slide wire corrections to 0.2 of a division; at 10 points of a straight wire; at 2 points per turn of a circular wire.

(d) Determination of corrections to standard cell dial settings to an accuracy of 0.01 per cent.

(e) Determination of reduction factors for low ranges to 0.01 per cent.

(f) Determination of the value of one main coil in terms of the international ohm to 0.01 per cent.

The corrections to the settings are expressed in fractions of a volt for the normal range. It is to be understood that when the range is changed by a given factor, the corrections, except those for the standard cell dial, are changed by the same factor. The corrections to the standard cell dial settings are given in percentage for the following reason: The electromotive force of the standard cell, and the resistance across which it is balanced, determine the current in the potentiometer. If this resistance departs from its nominal value, the current is thereby made to depart from nominal by the same percentage amount. Every setting is accordingly affected by the

same percentage error, and the corresponding percentage correction must be made. The signs of all corrections are so chosen that a positive sign means that the correction is to be added to the observed setting, a negative sign that the correction is to be subtracted. The correction to the reduction factors for low range are also given in per cent. The procedure, then, in applying the correction when a measurement is made on low range, is: first, add the volt corrections to the dial readings, then apply the percentage corrections for the current and the reduction factor, and then multiply the result by the nominal reduction factor.

The request for *test of a volt box* should state the conditions of its use, particularly the usual voltage. Test will be made either at low voltage or at maximum service voltage, as desired. It is recommended that tests be made at both low and maximum service voltage.

The multiplying factors furnished by the volt box should be integral numbers, adjusted to 0.1 per cent. The regular test will be a determination, at room temperature, of the multiplying factors to 0.01 per cent (and value of the total resistance in terms of the International Ohm).

F. PRECISION RESISTANCE APPARATUS—ACCURACY, GRADE B

See Fee Schedule 76, p. 29

Apparatus submitted for certification under this schedule must be of approved design and construction, and it is recommended that in general it satisfy the requirements laid down for precision resistance apparatus as given above. Apparatus which does not quite meet the requirements for a test under Schedule 75, but which is capable of giving the accuracy of this grade, may be accepted for test under this schedule.

Measurements will be made with the apparatus at the temperature of the room, and the results certified to an accuracy of 0.025 per cent, excepting resistances below 5 ohms. The latter will be certified to 0.001 ohm only. Potentiometers will be certified to an accuracy of two steps of the lowest dial or one-half division of the slide wire, except that the accuracy shall not exceed 0.025 per cent per coil of the first main dial.

G. PRECISION RESISTANCE APPARATUS; CHECKING—ACCURACY, GRADE C

See Fee Schedule 77, p. 29

Apparatus may be submitted under this schedule to determine whether a specified accuracy of adjustment, not better than 0.025 per cent, has been obtained; or, in the case of potentiometers, two steps of the lowest dial, or one-half division of the slide wire, accuracy not to exceed 0.025 per cent per coil of the first main dial. Coils of smaller value than 5 ohms will be checked not closer than 0.001 ohm. If all the coils are within the specified limit, the fees will be those given on page 29, under the corresponding Schedule 77. If any of the coils exceed the prescribed limit of adjustment, corrections will be given, and an additional fee will be charged for each such coil, equal to twice that of Schedule 75. If more than one-tenth of the coils thus exceed the limit of adjustment, the test will be made under Schedule 76.

H. ELECTRICAL PROPERTIES OF CONDUCTORS

See Fee Schedule 76, p. 30

Metallic wires or bars may be submitted for the determination of any one or more of the following electrical properties:

- (1) Resistance per unit length.
- (2) Resistance per meter-gram.
- (3) Resistance per centimeter cube.
- (4) The thermoelectric power against copper.
- (5) Temperature resistance formula (temperature coefficient).

For any of the resistance measurements, the specimen should have (a) a length of between 117 and 130 centimeters (46 and 51 inches); (b) an area of cross-section very uniform, not larger than 1 square centimeter, and preferably not smaller than 1 square millimeter; otherwise the test will be special. The specimen should be straight, and be in the condition as regards annealing, etc., in which the test is to be made. For the measurement of the thermoelectric power against copper, the specimen should preferably be in the form of a wire of 1 square millimeter or less in cross-section, and not less than 25 centimeters in length.

Samples are ordinarily returned to the sender unless the Bureau is otherwise directed. The purpose for which the test is desired should be stated in the application. If the sample is to be used as a standard in a conductivity bridge, the points at which calibration is desired should be stated.

When the test involves the measurement of the mass per unit length, the ends of the sample should be carefully squared to facilitate the accurate measurement of the total length.

On most specimens submitted for test, an accurate resistance measurement can only be made between potential connections, which are generally made by knife edges pressing lightly against the side of the specimen. The total resistance of the sample can not, therefore, be determined directly. The resistance per unit length is obtained by measuring the resistance of a known length of the sample, usually 1 meter.

The determination of the resistance per meter-gram involves measurement of the total length and mass of the sample, and the resistance of a known fraction of the total length. The calculation is based on the assumption that the remaining fraction has the same resistance per unit length as that between the potential connections.

The determination of the resistance per centimeter cube (the specific resistance or the reciprocal of the specific conductivity) involves the measurement of the mean cross-section, as well as the resistance of a known length. The mean cross-section may be obtained from micrometer measurements of the diameter at a number of points along the sample, but a better precision is generally obtained by measuring the total mass and length and the mean density. The measurement of the density is a tedious operation, and will not be undertaken in connection with regular tests under this schedule. For practical purposes it has been found that for copper an assumed density of 8.89 gives sufficiently accurate results.

In the case of copper, results can be expressed in terms of "percentage conductivity" of the Matthiessen standard, for measurements either of resistance per meter-gram or resistance per centimeter cube. The

Matthiessen standard represents the conductivity found by Matthiessen in 1862 for soft copper, which was supposed to be pure. However, improved methods of purification have resulted in the production of soft commercial copper having a percentage conductivity of over 100 per cent on this basis. The percentage conductivity of a sample on the "meter-gram basis" is the reciprocal of the ratio of its resistance at 20° C per meter-gram to a resistance of 0.15302 ohm⁴ per meter-gram at 20° C. The percentage conductivity on the "centimeter cube basis" is the reciprocal of the ratio of its specific resistance at 20° C in micro-ohms per centimeter cube to a specific resistance of 1.7213 micro-ohms per centimeter cube at 20° C. The two percentage conductivities are identical if the density of the sample is 8.89.

Since the data of value to the purchaser of conductors for power transmission, telegraphy, telephony, etc., is given by the "meter-gram" rather than the "centimeter cube" resistance, it is recommended that the former be used in the specification of conductors. The relative cost to such users of conductors of the same or even of different metals is given simply by multiplying the cost per unit mass by the resistance per meter-gram. (This statement of course neglects differences in insulation, differences of stranding of wires and cables, economy of space, etc.). The actual resistance per meter-gram at 20° C is preferred to percentage conductivity, because of the possible confusion in the use of the latter, and the fact that the use of the term "percentage conductivity" should be restricted to copper. Accordingly, to specify that the resistance per meter-gram shall be not greater than 0.1530 at 20° C is equivalent to specifying that the conductivity shall be not less than 100 per cent Matthiessen standard.

When a sample is submitted for the determination of the resistance per meter-gram, the resistance per meter and the mass per meter will be measured and given in the certificate. The computed resistance per meter-gram, and in the case of copper the percentage conductivity on the meter-gram basis, will also appear on the certificate.

When a sample is submitted for the determination of the resistance per centimeter cube (or specific resistance or conductivity), the resistance per meter, mean diameter, and mass per meter will be measured and given in the certificate. The certificate will also give the specific resistance, and in the case of copper the percentage conductivity, both calculated from the measured diameter, and on the meter-gram basis, calculated from the mass per meter. (This "meter-gram" percentage conductivity is identical with the "centimeter cube" percentage conductivity obtained on the assumption of a density of 8.89.) The latter method of determining the conductivity is not recommended; the meter-gram test contains everything but the cross-section measurement, which is very unreliable for small wires.

The resistance measurements of copper and aluminum may sometimes be made at a temperature other than 20° C. In such cases the value found will be corrected to 20° C, assuming, for the present, that the change in resistance per degree centigrade is 0.387 per cent of the value at 20° C, corresponding to a temperature coefficient of 0.42 per cent at 0° C.

⁴ This value for the resistance of the Matthiessen standard was obtained by applying the temperature coefficient found by Matthiessen to his value for the resistance at 0° C. A different 20° value is used to some extent elsewhere, derived by applying a more nearly correct temperature coefficient. But since Matthiessen's measurements at 20° C were as reliable as those at 0° C, it is clear that the use of the temperature coefficient he derived gives the correct weight to all his observations.

When a determination of temperature coefficient is desired, it will ordinarily be derived from measurements made at 20° C and 30° C.

The precision certified for resistance per unit length will be not better than 0.03 per cent, for resistance per meter-gram 0.05 per cent, and for resistance per centimeter cube 0.2 per cent. The precision given for a temperature coefficient will be that attainable by measurements of the resistance to 0.02 per cent, and of the temperature to 0.05°.

The thermoelectric power against copper of alloys to be used in resistance standards will be determined by connecting each end of the specimen to a copper wire and measuring the electromotive force in the circuit when one junction is at 20° C and the other junction at 30° C. The precision given will be that attainable by the measurement of the temperature difference to 0.05°, and the electromotive force to one microvolt, provided the specimen is sufficiently uniform to permit of this precision.

I. STANDARD CELLS

See Fee Schedule 79, p. 30

The recent improvements in the construction of Clark and Weston standard cells, obtained through a careful study of the methods of preparation and purification of the materials employed, has made it possible to set up cells from different materials agreeing with each other to two or three parts in 100 000. If the specifications published in Reprint 70, Bulletin of the Bureau of Standards, be followed, an accuracy of reproduction of at least 0.01 per cent should be attained, even under unfavorable conditions. The Weston normal cell, with its very small temperature coefficient and freedom from certain other defects, is to be preferred to the Clark. To secure the best results, such cells should be hermetically sealed, or sealed in such a manner that they can be placed in an oil bath without danger of developing a leak.

For all purposes except when the highest accuracy is sought the portable Weston cell, as put on the market by the Weston Electrical Instrument Company, and differing from the above only in that the solution of cadmium sulphate is saturated at approximately 4° C, has a considerable advantage. No oil bath is needed, and the change in electromotive force with temperature over a wide range is negligible for most purposes.

In view of the more limited accuracy of reproduction of the Clark cell, set up in accordance with the older specifications, and from which the basis of reference is derived, the results can only be certified to 0.02 per cent. Although the accuracy of reproducibility of the reference cells may be placed at two parts in 100 000, cells of the same type can be compared with an accuracy of one or two parts per million.

Cells submitted for certification will be measured at least twice against secondary standards known in terms of the reference cells of the Bureau. If the cells are so constructed that they can be measured in an oil bath, they will be measured at one temperature, 25° C, and otherwise at room temperature, which changes little during twenty-four hours, with a seasonal range of 22° to 28°.

J. SPECIAL TESTS

The special requirements of scientific investigators, manufacturers of apparatus, and others for higher precision than is considered in the foregoing schedules will be met as far as the regular work of the Bureau will

permit. In investigating the behavior of electrical standards, variations are noted with certainty in a shorter time when the precision of measurement is high. The Bureau will gladly cooperate with those who need the highest precision in their work, both in the design and testing of apparatus.

A few suggestions in regard to resistance apparatus of the highest precision will be given here. To attain a higher accuracy than 0.01 per cent, the variation of the resistances with temperature must be considered. For efficient temperature control oil immersion is essential, and either the variation of the resistances with temperature should be known, and the temperature determined during measurements; or the oil should always be brought to the temperature of the calibration whenever the apparatus is used. Some means for stirring the oil is also desirable. The use of oil also enables the use of higher currents in the coils, as the heat is more readily dissipated in the oil. Oil immersion also reduces thermoelectric troubles of slide wires. It is recommended that the containing case be sealed, thus protecting the resistances from the action of atmospheric moisture. Where accurate calibration of coils under 10 ohms is desired, auxiliary potential connections to the terminal blocks are indispensable. Such connections must also be provided to the branch points and terminals of ratio coils under 100 ohms. Coils are usually connected to the blocks through copper posts. Frequently each block carries only one such post, and the terminals of adjacent coils are both soldered to its end. This construction is satisfactory for coils greater than 100 ohms, but to avoid errors in calibration of the lower values a separate post should be provided for the connection of each coil to the block. If the highest precision is desired in the use of the lower resistances, switches and plugs are unsatisfactory, and recourse must be had to the use of mercury contacts. Such contacts, when kept clean, are constant to 0.000002 ohm. Caution is however required to avoid short-circuiting the coils by stray drops of mercury between the blocks. This trouble may be eliminated by raising each metal block up on an insulating block.

Tests made to a higher accuracy than 0.01 per cent; tests of bridges, etc., at other than room temperatures; and, in general, approved tests not provided for in the other schedules, will be considered special, and a special fee will be charged for them. The application for a special test should state fully the purpose for which the apparatus has been used or is to be used in the future, the need for the test, and the precision desired. The test should be arranged for by correspondence before shipment of the apparatus. The special fee charged will depend chiefly upon the time consumed and the amount of alteration required in the regular bureau testing set-ups. An estimate will be given when possible.

6. CERTIFICATES AND REPORTS

When apparatus submitted fulfills the requirements for certification, it will be tested and given a certificate of corrections. The certificate can only indicate the corrections of the apparatus at the time of the test, and does not guarantee the constancy of the values. When there are defects which exclude an apparatus from certification, a report will be rendered giving such information as we have found. In such cases, a special fee will be charged, depending upon the time consumed.

7. GENERAL INSTRUCTIONS TO APPLICANTS FOR TESTS

APPLICATION FOR TEST.—The request for test should be made in writing, addressed to "Bureau of Standards, Washington, D. C.," and should enumerate the articles submitted for test, giving the identification marks of each—for example, maker's name and number—and should state the nature of the test desired.

NATURE OF TEST.—The classification of tests in this circular should be followed, and the schedule numbers above should be used to indicate the test desired. Applicants for the Grade A tests should state the character of the work for which the apparatus is to be employed. When the desired test is not included under the regular schedules, the applicant must comply with the requirements for special tests on page 24. When apparatus is sent simply for test, without definite instructions, the Bureau will, if practicable, decide upon the nature of the test.

CONDITION OF APPARATUS.—Before submitting apparatus for test, the applicant should ascertain that it fully satisfies the requirements for the test desired. The specifications for the various kinds of apparatus are given in the separate schedules above; these are in general liberal, but represent what experience has shown to be necessary for reliability. Apparatus of radically new design, or otherwise not included in the specifications, will be considered on its merits. All apparatus must be in good working condition; the insulation must be adequate, and contacts must be clean, etc. No repairs will be made; if they are needed, they should either be made by the applicant or the apparatus should be sent to the maker before submitting for test. All possible care will be taken in handling apparatus, but the risk of injury or breakage in shipment or under test must be borne by the applicant.

IDENTIFICATION MARKS.—All packages should bear the shipper's name and address and, when convenient, a list of the contents.

Each separate piece of apparatus, resistance standard, standard cell, or sample of material should be provided with an identification mark, which in most cases may be the maker's name and number. The identification mark should be given in the application for the test.

SHIPPING DIRECTIONS.—Apparatus or test specimens should be securely packed in cases or packages which will not be broken in transportation. The shipment in both directions is at the applicant's risk. To facilitate packing and shipping, the tops of the cases should have the return or forwarding address on the under side and should be put on with screws. Transportation charges are payable by the party desiring the test and must be prepaid. Unless otherwise arranged articles will be returned or forwarded by express "collect."

RETURN OF APPARATUS.—Regular tests will be made in the order in which the applications are received, except as this practice may be varied by grouping similar tests together. It is therefore suggested that the applicant make request for a test from two weeks to a month preceding the shipment of the apparatus. This facilitates the work of the Bureau, as well as the prompt return of the apparatus.

ADDRESS.—Apparatus submitted for test, as well as all correspondence, should be addressed simply "Bureau of Standards, Washington, D. C." Apparatus delivered in person or by messenger should be accompanied by a written request for the test.

REMITTANCES.—Fees should be sent with the request for test, in accordance with the foregoing schedules, or promptly upon receipt of bill. Certificates are not given nor is apparatus returned until the fees due thereon have been received. Remittances may be made by money order or check drawn to the order of the "Bureau of Standards."

8. OTHER ELECTRICAL TESTING

In addition to the electrical testing described in this circular, the Electrical Division of the Bureau undertakes other tests, as follows:

The testing of electrical measuring instruments is described in full in Circular No. 20; the accurate determination of the constants of condensers and inductance coils will be covered by a circular soon to be issued; magnetic testing is described in Circular No. 17. These circulars will be sent to interested parties on request.

9. SCHEDULES OF FEES FOR TESTING

SCHEDULE 71

Precision Resistance Standards

Grade A.—Maximum accuracy, 0.005 per cent

Denomination	Accuracy	I		II	III	IV
		Number of temperatures	Fee	Extra fee for additional measurement	Fee for measurement at 25° C, standards previously certified	Fee for measurement at 25° C, standards not previously certified
	<i>Per cent</i>					
(a) 1 ohm	0.005	3	\$4.00	\$1.25	\$2.00	\$2.50
(b) 10 "	.005	3	4.00	1.25	2.00	2.50
(c) 100 "	.005	3	5.00	1.50	2.50	3.00
(d) 1000 "	.005	3	5.00	1.50	2.50	3.00
(e) 10000 "	.01	2	5.00	1.50	2.50	3.00
(f) 100000 "	.02	2	5.00	1.50	2.50	3.00
(g) 0.1 "	.005	3	4.00	1.25	2.00	2.50
(h) 0.01 "	.005	3	5.00	1.50	2.50	3.00
(i) 0.001 "	.01	2	5.00	1.50	2.50	3.00
(j) 0.0001 "	.01	2	6.00	2.00	3.00	3.50

(k) For standards having values 2, 3, 4, or 5 times any of the above, and between 1 and 100 000 ohms, the fees will be 30 per cent additional.

The additional fee of II is either for a measurement made a month or more after the I measurement, the standard remaining at the Bureau between the measurements, to determine the constancy of the standard over that interval; or, for an additional measurement with a current larger than the usual test current.

Under III are included standards certified at the national testing laboratories of Germany, England, or France, accompanied by certificate, as well as standards previously certified at this Bureau.

SCHEDULE 72

Precision Resistance Standards

Grade B.—Maximum accuracy, 0.025 per cent

(Fees for measurement at one temperature, 25° C.)

(a) 1, 10, and 0.1 ohm standards.....	\$1.50
(b) 100, 1000, 10 000, 0.01, and 0.001 ohm standards.....	2.00
(c) 100 000 and 0.0001 ohm standards.....	2.50

(k) For standards having values 2, 3, 4, or 5 times any of the above, the fees will be 30 per cent additional.

SCHEDULE 73

Resistance Standards for Current Measurement

Grade A.—Accuracy, 0.01 per cent

Denomination	I Measurement at room temperature with low test current	II Extra fee for additional measurement with low test current, 10° above room temperature	III Extra fee for additional measurement with test current not exceeding—
(a) 1. ohm	\$2.50	\$2.00	3 amp., \$1.00
(b) .1 "	2.50	2.00	15 " 1.25
(c) .01 "	3.00	2.00	100 " 1.50
(d) .001 "	3.50	2.00	500 " 1.75
(e) .0001 "	4.00	2.00	1000 " 2.00

(k) For standards having values 2, 3, 4, or 5 times any of the above, the fees will be 40 per cent additional.

"Low test current" above signifies a test current so small as to produce no appreciable heating of the standard.

SCHEDULE 74

Resistance Standards for Current Measurement

Grade B.—Accuracy, 0.025 per cent

Denomination	I Measurement at room temperature with low test current	II Extra fee for additional measurement with test current not exceeding—
(a) 1. ohm	\$2.00	3 amp., \$0.75
(b) .1 "	2.00	15 " 1.00
(c) .01 "	2.50	100 " 1.25
(d) .001 "	3.00	500 " 1.50
(e) .0001 "	3.50	1000 " 1.75

(k) For standards having values 2, 3, 4, or 5 times any of the above, the fees will be 40 per cent additional.

SCHEDULE 75

Precision Resistance Apparatus

Grade A.—Accuracy (in general), 0.01 per cent

(a) Minimum fee for each piece of apparatus.....	\$3.00
(b) Rheostats, bridges (excepting ratio coils), potentiometers (excepting coils for reducing range), etc., per coil.....	.25
(c) Ratio coils of bridges, per coil.....	.50
(d) Calibration of slide wire, per point.....	.25
(e) Reduction factors for potentiometer, per factor.....	2.00
(f) Cleaning contacts, per contact.....	.10
VOLT BOXES, FACTORS—	
(g) Test with low voltage, per factor.....	1.50
Test with service voltage (maximum 750 volts)—	
(h) factors 2, 3, 5, or 10, each.....	2.00
(i) factors 20, 30, 50, or 100, each.....	3.00
(j) factors 200, 300, 500, or 1000, each.....	4.00

SCHEDULE 76

Precision Resistance Apparatus

Grade B.—Accuracy (in general), 0.025 per cent

(a) Minimum fee for each piece of apparatus.....	\$2.50
(b) Rheostats, bridges (excepting ratio coils), potentiometers (excepting coils for reducing range), etc., per coil.....	.20
(c) Ratio coils of bridges, per coil.....	.40
(d) Calibration of slide wire, per point.....	.20
(e) Reduction factors for potentiometers, per factor.....	1.50
VOLT BOXES, FACTORS—	
(f) Test with low voltage, per factor.....	1.00
Test with service voltage—	
(g) factors 2, 3, 5, or 10, each.....	1.50
(h) factors 20, 30, 50, or 100, each.....	2.50
(i) factors 200, 300, 500, or 1,000, each.....	3.50

SCHEDULE 77

Precision Resistance Apparatus

Grade C.—Checking to an accuracy of 0.025 per cent

(a) Minimum fee for each piece of apparatus.....	\$2.00
(b) Rheostats, bridges (excepting ratio coils), potentiometers, etc., per coil.....	.15
(c) Ratio coils of bridges, per coil.....	.30
(d) Calibration of slide wire, per point.....	.15
(e) Reduction factors for potentiometers, per factor.....	1.00
VOLT BOXES, FACTORS—	
(f) Test with low voltage, per factor.....	1.00
Test with service voltage—	
(g) factors 2, 3, 5, or 10, each.....	1.25
(h) factors 20, 30, 50, or 100, each.....	2.00
(i) factors 200, 300, 500, or 1000, each.....	3.00

NOTE.—If the accuracy of adjustment is found not to be within the limits specified throughout, an additional fee will be charged (see p.21).

SCHEDULE 78

Electrical Properties of Conductors

(a) Resistance per unit length.....	\$2.00
(b) Resistance per meter-gram.....	3.00
(c) Specific resistance (and percentage conductivity).....	4.00
(d) Resistance temperature formula.....	5.00
(e) When the resistance is less than .001 ohm per meter, additional fee.....	1.00
(f) For the calibration of standards for conductivity bridges (the fee may depend on the time required in making the test), per point.....	2.00
(g) Thermoelectromotive force against copper.....	2.50

SCHEDULE 79

Standard Cells

Accuracy, 0.0002 volt

(a) Testing standard cells at one temperature, about 25° C.....	\$2.00
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S. W. STRATTON,
Director.

Approved:

CHARLES NAGEL,
Secretary.

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CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 22

STANDARD SPECIFICATIONS FOR TRANSFORM-
ERS, OIL-IMMERSED, SELF-COOLED,
60-CYCLE, 2200 VOLTS

[1st Edition]

Issued May 15, 1910



WASHINGTON
GOVERNMENT PRINTING OFFICE
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These specifications have been drawn up with the purpose of providing a standard specification for the purchase of transformers of the type most commonly used both by the government departments and by other purchasers. They have been so drawn as to secure the most serviceable apparatus on the market, and at the same time to admit the regular product of reputable manufacturers. To this end the cooperation of government engineers and of representatives of many of the leading manufacturers has been secured, and it is largely due to help and criticism from these sources that the specifications are representative of the best practice among manufacturers.

The specifications are based upon those issued by the Navy Department in 1908, and known as "2T3," but have been considerably changed with a view to admitting all reliable makes of transformers without opening any loopholes for the introduction of inferior apparatus. There is no doubt still room for improvement, and any suggestion to this end from either manufacturers or users will be welcomed, and will receive careful consideration in revising the specifications from time to time.

The specifications may be used for transformers of other frequencies, voltages, etc., by appropriate changes in the numerical values.

S. W. STRATTON, *Director.*

STANDARD SPECIFICATIONS FOR TRANSFORMERS, OIL-IMMERSED, SELF-COOLED, 60-CYCLE, 2200 VOLTS

PROPOSALS

1. Bidders shall include in their proposals complete information with reference to the following characteristics of the transformers which they offer, and no bid will be considered with guarantees inferior to those specified in Table I.

Core loss.

Copper loss under full load.

Efficiency.

Regulation.

Weight.

Dimensions (sketch or drawing).

These data shall apply to a temperature of 25° C. All other factors being equal, preference will be given to the apparatus having the best performance characteristics.

GENERAL

2. **Type, Frequency, and Voltage.**—These transformers shall be either of the shell type or of the core type; shall be oil-immersed and designed for operation on 60-cycle circuits. The primary voltage shall be 2200, and the secondary shall be so arranged that either 110 or 220 volts may be obtained with 2200 volts on the primary.

3. **Materials and Workmanship.**—The materials entering into the construction of these transformers shall be of the highest grade, and of a quality and character best suited to the purpose in hand. The workmanship shall be first class in every respect and shall meet with the approval of the representative of the purchaser.

4. **Rating.**—Transformers shall be rated at the number of kilowatts which they can deliver without exceeding the specified rise of temperature when operating at unity power factor, and under normal conditions of frequency and secondary voltage.

5. **Name Plate.**—Each transformer shall bear a name plate, which shall state name of maker, serial number, type, and kilowatt capacity of the transformer, also the primary and secondary voltages and the frequency for which the transformer is designed.

DETAILS OF CONSTRUCTION

6. **Cases.**—Transformer cases shall be made of cast iron or of sheet iron fastened to cast-iron bases in a satisfactory manner and provided with cast-iron covers. Eyebolts or hooks shall be provided for handling the transformers filled with oil. Cases shall be free from leaks, and shall be impervious to oil. Covers shall be provided with felt or other suitable gaskets. The cases of all transformers above 5 kilowatts capacity shall be provided with oil plugs for removing the oil from the case. Oil gages

shall be provided for any individual case where conditions render their use expedient, and in such instances they will be separately specified.

7. **Hangers and Cut-outs.**—Unless specified to the contrary, transformers up to 50 kilowatts shall be provided with hanger irons for supporting the transformers when mounting same on poles. Two plug cut-outs shall be provided for the high-tension side of each transformer.

8. **Leads and Connection Boards.**—Four secondary leads shall be brought out of the case through porcelain bushings, which shall be sealed into the case with a suitable compound which will not soften sufficiently to flow at any temperature less than 90°C . Two primary leads shall be brought out in a similar manner. The ends of the primary coils shall be brought to a convenient connection board of porcelain or other suitable material within the case, and so arranged that the primary coils may be put in series or in multiple.

9. **Core.**—The core shall be built of laminated sheet steel, so firmly assembled that no buzzing is perceptible, and shall be nonaging. At the option of the purchaser an artificial aging test may be made upon a sample of the core material or upon a finished transformer.

10. **Windings and Insulation.**—The primary coils shall be insulated from the secondary by a shield of ample dielectric strength. Each turn shall be thoroughly insulated, and the voltage between adjacent turns kept as low as is consistent with good design. Coils shall be carefully taped and leads shall be brought out in a thoroughly workmanlike manner. Coils shall be dried by the vacuum process, and impregnated with an insulating compound which is not hygroscopic and not soluble in nor acted upon by the transformer oil at operating temperatures, or else the insulating material used shall be moisture proof. The windings shall be so disposed as to permit the free circulation of oil and the maintenance of a nearly uniform temperature throughout.

11. **Oil.**—The oil used in these transformers shall be a pure mineral oil obtained by the fractional distillation of petroleum, unmixed with any other substance. It shall be prepared and refined especially for the purpose, and shall be free from moisture, acid, alkali, and sulphur compounds. The flash point of the oil, determined in a closed cup, shall be not less than 170°C , and on cold test it shall not begin to solidify, and no wax shall form in the oil above 0°C .

Sufficient oil shall be furnished to completely immerse core, windings, and connection board.

The oil shall withstand a breakdown test of 30 000 volts between spherical surfaces of 0.5 cm radius, 0.40 cm apart.

TESTS AND PERFORMANCE

12. **Inspection Requirements.**—All transformers will be tested at the place of manufacture, in the presence of a representative of the purchaser, if the latter so desires. The contractor shall give ten days' notice to the purchaser of his readiness to make the specified tests, and shall furnish all labor, materials, instruments, observers, complete facilities for tests, including those enumerated in paragraph No. 14, and such information regarding the transformers as is available without additional tests, as the

purchaser's representative may consider necessary for a definite opinion of their acceptability. He shall permit the representative to examine the transformers at all times from the beginning of their manufacture. The results of all tests specified herein shall be given by the manufacturer to the purchaser or his representative in the form of a certified report.

13. **Description of Tests.**—The following tests will be made upon all of the transformers:

(a) *Design, materials, and workmanship.*—Action upon these features will be based on the requirements of the specifications and observations made while the apparatus is under test.

(b) *Core loss.*—Core loss and exciting current shall be taken cold at approximately 25° C. Core loss shall be measured with a wattmeter at normal frequency and voltage, using power from a generator giving a sine wave, when such is available. When a pure sine wave is not available, it shall be permissible to use any wave form which comes within the A. I. E. E. definition of a sine wave, adjusting the test voltage so that the core loss will be the same as with normal voltage and sine wave. Where voltage can not be regulated by excitation of the generator, it must be done with auto-transformers and not by rheostats in series with the transformer to be tested. The average of the core losses of the full number of transformers of the same size on one order shall not exceed the value stated in the proposal, and the maximum core loss must in no case exceed this value by more than 10 per cent.

(c) *Exciting current.*—The exciting current, as observed during the test for core loss, shall in no case exceed 10 per cent of the full load current, and for transformers of 10 kw or larger, shall not exceed 8 per cent of full load current. With an applied voltage 10 per cent above normal, the exciting current shall not exceed 20 per cent of the full load current.

(d) *Copper loss.*—The copper loss shall be determined by separate measurements of primary and secondary resistance at or corrected to 25° C. The average copper loss of the full number of transformers of the same size on one order shall not exceed the value of copper loss given for that size in the proposal, and the maximum copper loss must in no case exceed this value by more than 10 per cent.

(e) *Regulation.*—The regulation shall be computed from the measured resistances and the reactive drop of voltage, using the following expressions.

For unity power factor:

$$\text{Per cent regulation} = \frac{100 IR}{E} \quad (1)$$

For 60 per cent power factor:

$$\text{Per cent regulation} = 100 \left(\frac{0.6 IR + 0.8 P}{E} \right) \quad (2)$$

where E is the rated primary voltage, P the reactive drop of voltage, I the full load primary current (not including exciting current). The equivalent resistance, R , of primary and secondary combined, is found by multiplying the secondary resistance by the square of the ratio of turns, and adding to the primary resistance.

The impedance voltage, e , is found by short-circuiting the secondary winding, and measuring the voltage necessary to send full-load current

through the primary. The reactive drop is then computed from the expression

$$P = \sqrt{e^2 - I^2 R^2} \quad (3)$$

The per cent regulation computed in this way shall not exceed the values given in Table I. Under conditions of maximum unbalancing, that is, with full-load current on one side and no load upon the other side, the difference in voltage shall not exceed the stated per cent regulation.

(f) *Heating*.—The two transformers of each size whose combined core and copper losses come nearest to the values stated in the proposal shall be selected for a heating test of that type and size. They may be overloaded and overexcited to hasten the rise of temperature to the ultimate value under constant full load, and the final temperature in any part, maintained for one hour under constant full load and normal voltage and frequency, shall not exceed the temperature of the room (corrected to 25° C) by more than 50° C. The rise of temperature shall be determined by the increase of resistance of the windings and by thermometer in the oil, placed as directed by the representative of the purchaser, and the highest indicated temperature shall be taken to determine the rise.

If the test be not made with sine wave and rated frequency, the applied voltage shall be adjusted to make the core loss the same as when operating on sine wave of normal voltage and frequency. The load current in amperes shall be based upon rated volts and watts.

The transformers may be loaded with a noninductive load, or they may be subjected to loading conditions by the opposition method.

The rise of temperature of other transformers of the same size and type shall be computed from the sum of core and hot copper losses on the assumption that the temperature rise is proportional to the combined losses. The hot copper loss shall be computed on the assumption of a proportional increase over the cold copper loss, equal to the average proportional increase in the two transformers subjected to heating test.

Any transformer in which the computed temperature rise exceeds the above limits shall be rejected, or, at the option of the manufacturer, subjected to an actual heating test.

(g) *Insulation*.—The transformers shall withstand for one minute an alternating electromotive force of 10 000 volts, 60 cycles, between primary coil and core, case and secondary coil, and 4000 volts between secondary coil and core and case. Transformers shall also withstand for one minute twice the rated voltage applied to the primary coil. These tests are to be made before oil has been put in the cases.

At the end of the heating run, the insulation tests shall be repeated upon the two hot transformers while filled with oil.

MANUFACTURER'S FACILITIES

14. The manufacturer shall provide complete and suitable equipment for making tests, which shall include the following:

- (a) A source of supply of approximately sine wave and rated frequency.
- (b) Means for tracing wave forms or determining the correction necessary in order to get sine-wave results.

(c) Means for determining the frequency, by tachometer connected to the generator, or by frequency meter of the vibrating-reed type.

(d) Calibrated instruments of suitable capacity for measuring watts, volts, and amperes.

(e) Apparatus for accurate measurement of resistance, preferably by the drop of potential method.

(f) Apparatus for high-potential insulation tests, including spark gap for measurement of applied voltage.

(g) Facilities for flash point, evaporation, dielectric strength and cold tests of transformer oil.

(h) Suitable means for loading transformers by opposition, or else water rheostats or lamp banks for direct noninductive loading.

BASIS FOR COMPARING GUARANTEES

15. In case the proposals offered by different bidders in accordance with these specifications guarantee core losses less than those specified in Table I, each watt of difference shall be evaluated at \$0.88 for purposes of comparison. For the same purpose, copper loss shall be evaluated at \$0.33 per watt for each watt difference between values specified in Table I and the full-load value guaranteed by the bidder.

REJECTION OPTIONAL

16. In case transformers submitted under these specifications show upon test average core or copper losses in excess of those stated in the proposal, the purchaser shall have the option of accepting them at a reduction from the price bid, the reduction to be determined by making the same allowance per watt for the excess loss as specified under section 15.

TABLE NO. I
Maximum Core and Copper Losses

Rating in Kilowatts	Core Loss in Watts	Copper Loss in Watts at Full Load	Per Cent Regulation	
			Power Factor =1.00	Power Factor =0.60
1	21	26	2.6	3.1
1.5	26	36	2.5	3.1
2	30	46	2.4	3.1
2.5	33	55	2.3	3.1
3	36	64	2.2	3.1
4	41	80	2.1	3.2
5	45	93	2.0	3.2
7.5	64	125	1.9	3.2
10	82	160	1.7	3.2
15	110	216	1.6	3.2
20	135	280	1.5	3.2
25	160	323	1.4	3.2
30	175	374	1.3	3.2
40	210	470	1.2	3.2
50	255	580	1.2	3.3
75	400	875	1.1	3.3
100	560	1000	1.0	3.4

NOTES TO THE SPECIFICATIONS

9. An artificial aging test, carried out by maintaining the core material at a temperature between 90° and 100° C for two weeks, is a sufficient indication of this property of the core. If the core losses increase by as much as 5 per cent during this treatment, the transformers should be rejected.

Silicon steel of good quality is practically nonaging, and as the performance characteristics necessitate the use of this material, there is little danger of aging. When an aging test is required, the cost should be borne by the purchaser. In the case of purchases by bureaus of the Government, such tests, if desired, can be carried out at the Bureau of Standards at the expense of the Government.

11. The presence of nonmineral oils, except rosin oil, can be detected by heating to 240° C with solid caustic potash. Foaming during heating, or gelatinization within a half hour after cooling, indicates the presence of fat or fatty oil. Rosin oil can be detected by shaking the oil with half its volume of acetic anhydride, and allowing the two layers to separate. On adding one or two drops of sulphuric acid (about 1.58 sp. gr.) the presence of rosin oil is indicated by a reddish-purple coloration.

Addendum to 11.—The breakdown test will be sufficient evidence of absence of moisture. Admixture of volatile oils will be shown by a flash at low temperature, which may not be repeated upon successive trials. The lowest temperature at which a flash is obtained should be taken as the flash point. Breakdown and flash-point tests should be made on every lot of oil; other tests only when considered necessary by purchaser.

For breakdown test see note to section 13 (g).

13 (b). The Standardization Rules of the American Institute of Electrical Engineers contain the following:

80. A maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

81. The deviation of wave form from the sinusoidal is measured by determining the form by oscillograph or wave meter, computing therefrom the equivalent sine wave of equal length, superposing the latter upon the observed wave in such a manner as to give the least difference, and then dividing the maximum difference at any ordinate by the maximum value of the equivalent sine wave.

82. The equivalent sine wave is a sine wave having the same frequency and the same effective (or root of mean square) value as the actual wave.

When the form factor of the wave is determined without actually tracing the wave, it should come within the limits of 1.07 and 1.17.

The core loss is made up of two parts, the one due to hysteresis, the other to eddy currents. For a given frequency the latter depends only upon voltage, while the hysteresis depends also upon the form factor of the wave, and is proportional to some power (usually taken as 1.6) of the quotient of voltage divided by form factor. The correct hysteresis loss is obtained by making the voltage proportional to the form factor, the normal voltage corresponding to a form factor of 1.1106. The voltage necessary to give the correct total loss depends upon the ratio of hysteresis loss to eddy current loss. If the hysteresis is h per cent of the total, a sufficiently approximate correction to the voltage is h per cent of f per cent, where f is the percentage by which the form factor differs from 1.11. The percentage of

hysteresis need not be known accurately, and will usually lie between 70 and 80 for a 60-cycle transformer.

If a "core-loss voltmeter" be used to correct for wave form, it should be calibrated for about the same proportion of hysteresis and eddy current losses as applies to the transformers tested. A transformer of the same type and voltage whose core loss has been determined at some standardizing laboratory upon sine wave may be used in correcting the voltage. Evidence of such test must exist in the form of a certificate with date anteceding that of the present test by less than one year.

A tolerance of two cycles in the adjustment of frequency may be allowed, that is, the frequency must be between the limits of 58 and 62 cycles per second, and the effect of frequency upon the core loss may be neglected when within these limits.

13 (d). A check on the determination of copper loss by resistance measurement should be made by a measurement by wattmeter, and result reported in certificate.

13 (e). The complete expression for regulation at unity power factor is

$$\text{Per cent regulation} = 100 \left[\frac{IR}{E} + \frac{1}{2} \left(\frac{P}{E} \right)^2 \right] \quad (4)$$

and at 60 per cent power factor is

$$\text{Per cent regulation} = 100 \left[\frac{0.6 IR + 0.8 P}{E} + \frac{1}{2} \left(\frac{0.8 IR - 0.6 P}{E} \right)^2 \right] \quad (5)$$

but the terms omitted in the simpler expressions (1) and (2) affect the result by only a few hundredths of 1 per cent, and this much margin is allowed the manufacturer for the sake of simplifying the computation.

13 (f). In computing rise of temperature and in correcting results to a room temperature of 25° C, the Standardization Rules of the A. I. E. E. shall be followed. Appendix E of said rules gives the temperature coefficient for resistance of copper for any initial temperature, based upon the relation

$$R_t = R_o(1 + .0042 t) \quad (6)$$

where t is the temperature in degrees centigrade. According to Rule 269, the observed rise of temperature should be corrected by one-half per cent for each degree of difference of room temperature from 25° C.

In adjusting the voltage to give the proper core loss, correction for wave form should be made as stated under 13 (b). If the frequency differs appreciably from normal, an additional correction therefor should be made to the voltage, of a percentage equal to three-tenths of the percentage by which the frequency differs from the normal.

Independent adjustments may be made of the voltage to give proper core loss, and of the load current to give proper copper loss.

In the opposition method of loading, one winding (say primary) of each transformer is connected to a line supplying the proper voltage to excite the cores. The other windings (say secondary) are connected in series with each other and with an ammeter and auxiliary transformer which is excited

until full load current is indicated upon the ammeter. This auxiliary transformer must be supplied from the same source which is exciting the cores.

13 (g). The specified voltages should be determined by spark gap measurements. When a sine wave is used in the test, static voltmeters or calibrated transformers may be used for measuring the voltage. When a spark gap is used, Appendix D of the A. I. E. E. Standardization Rules shall apply. Rules 218, 224, 229, 233, 234, 235, 236 should be observed in making this test. In applying double voltage to the primary, a frequency higher than normal may be used.

15. The valuation to be put upon core and copper losses should be fixed to suit the cost of power and conditions of use affecting any particular installation.

This section may be omitted when it is desired to award contract to lowest bidder regardless of performance guarantees.

The values given are computed upon a cost for core loss of 1 cent per kilowatt hour, for copper loss of 3 cents per kilowatt hour; interest and depreciation are assumed at 10 per cent; copper loss is based upon full load for three hours per day, core loss running on constantly. Since the valuation is proportional to the time and to the cost of power, and inversely proportional to the percentage for interest and depreciation, the figures given can be easily altered to suit other conditions. Thus, if power costs 3 cents for core loss and 6 cents for copper loss, the valuations should become \$2.63 and \$0.66 per watt, whereas if all power costs 1 cent per kilowatt hour, the valuations should become \$0.88 and \$0.11. Different costs for core and copper loss have been assumed in recognition of the fact that power is worth more at the time of peak load than during the remainder of the twenty-four hours.

Table I.—These limitations of values have been chosen so as to assure good design for average conditions. In particular cases it will be advantageous to waive these limits in order to secure transformers best suited to the purpose. Thus, if power be very cheap or the transformers be not excited throughout the twenty-four hours, it will be advisable to increase core losses and decrease copper losses. This would be further indicated by the valuation put upon the losses in section 15.



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DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR
OF THE
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S. W. STRATTON, DIRECTOR

No. 23

**STANDARDIZATION OF
ELECTRICAL PRACTICE IN MINES**

[1st Edition]
Issued July 15, 1910



WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

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INTRODUCTION

In publishing at this time the first portion of the results of the work that has been done by the Bureau of Standards on the subject of the Standardization of Electrical Practice in Mines it is proper to explain the circumstances under which the work was taken up.

On March 11, 1909, the following letter was received from the secretary of the American Mining Congress:

THE AMERICAN MINING CONGRESS,
Denver, Colo., March 6, 1909.

S. W. STRATTON,
Director Bureau of Standards, Washington, D. C.

MY DEAR SIR: At the recent session of the American Mining Congress held at Pittsburg, Pa., a resolution offered by David B. Rushmore, of Schenectady, N. Y., as amended by the committee on resolutions, was adopted by the convention. Copy of these resolutions, as adopted, is herewith inclosed.

Our board of directors have requested me to ask you to accept a place upon this committee as the independent electrical engineer.

The representatives of the manufacturers selected are: David B. Rushmore, of Schenectady, N. Y., representing the General Electric Company, and W. A. Thomas, of Pittsburg, Pa., representing the Westinghouse Electric & Mfg. Co.

It is proposed to ask the coal operators to select two members, and that the U. M. W. of A. and the A. F. of L. shall each be requested to choose a member to represent the miners. It has been thought best to have the membership of this committee centralized in the eastern portion of the country, in order that the attendance of the members of the committees at its meetings may be more easily secured. While it is not customary for this organization to go outside of its members in the appointment of its committees, yet this seems to be a committee requiring that this course shall be pursued, and we greatly hope that you will be willing to undertake this service, and that through the work of this committee much good may be accomplished. I shall also hope, through your connection with this committee, to have the pleasure of meeting you personally, and that through this work the Bureau of Standards and our organization may be brought into a close working sympathy.

Trusting that we may have an early and favorable response, I am,

Very respectfully, yours,

(Signed) JAMES F. CALLBREATH, Jr.,
Secretary.

The resolution referred to in the above letter, authorizing the appointment of a standing committee to standardize electrical practice in mining work, is as follows:

RESOLUTION NO. 7. INTRODUCED BY DAVID B. RUSHMORE, OF NEW YORK

Whereas the use of electricity in mines is increasing rapidly, and numerous small bodies are attempting to independently standardize the practice regarding its use, and as this subject can be best handled by a national body working in harmony with all the different interests concerned;

Therefore be it recommended, that a standing committee be appointed by the president of the American Mining Congress to standardize as far as possible and make recommendations concerning electrical practice in mining work, said committee to consist of seven members, as follows, viz: One electrical engineer, two representatives of the manufacturers of electrical equipment, two representatives of the labor organizations, and two mine operators.

The following reply was sent to Secretary Callbreath's letter:

DEPARTMENT OF COMMERCE AND LABOR,
BUREAU OF STANDARDS,
Washington, March 16, 1909.

Mr. JAMES F. CALLBREATH, Jr.,
Secretary The American Mining Congress, Denver, Colo.

MY DEAR SIR: I beg to acknowledge the receipt of your letter of March 6, requesting me to accept a place upon the committee to standardize electrical practice in mining work. In reply I would state that I would be pleased to do so, but I believe you would get better results from Dr. Edward B. Rosa, head of the electrical division of the bureau.

I am not only in sympathy with the work that you propose, but take this opportunity to offer your committee the services of the bureau in any way that may be possible.

Thanking you for your interest in the matter, I remain,
Yours, very truly,

(Signed) S. W. STRATTON,
Director.

The following letter, accepting the services of the Bureau of Standards, was received March 26:

THE AMERICAN MINING CONGRESS,
Denver, Colo., March 22, 1909.

Mr. S. W. STRATTON, *Director,*
Bureau of Standards,
Department of Commerce & Labor,
Washington, D. C.

MY DEAR SIR: Your kind favor of March 16 is received. I greatly appreciate the kind words of your letter, and will accept and act upon your suggestion of the appointment of Dr. Edward B. Rosa upon the committee mentioned. I am writing to Doctor Rosa by this mail, and I am sure that the committee will be glad to avail itself of your kind offer of the services of the Bureau of Standards in connection with this work.

Thanking you for your interest in this matter, I am,
Very respectfully, yours,

(Signed) J. F. CALLBREATH, Jr.,
Secretary.

Accordingly, Dr. Rosa was appointed chairman of the committee, and six others, representing the manufacturers, the mine operators, and the mine workers, were appointed in accordance with the resolution. The chairman was notified of the appointment of the last member of the committee in a letter from the secretary dated August 5, 1909.

The first work that would naturally be taken up by the committee was a study of existing practice and of the laws and regulations under which electrical apparatus is now installed and operated. Then would follow a careful study leading to standardization of voltages, of electrical machinery intended for use in mines, and of methods of insulation of circuits, and of installation of machines. To do the subject justice obviously required a large amount of work and study, and yet the members of the committee were all very busy men and the American Mining Congress had provided no money to defray the expense of such an investigation. It appeared necessary for the Bureau of Standards to do a much larger share of the work than was at first contemplated, and accordingly a competent and experienced electrical engineer of the bureau staff, Mr. Burton McCollum, was detailed to assist the chairman of the committee in carrying on the work that had been undertaken. Such work is directly in line with the work of the bureau. The bureau is represented on the Standardization Committee of the American Institute of Electrical Engineers, and on the technical committees of several other engineering societies, and some of its

investigations have been undertaken in aid of the work of such committees. To aid in securing uniformity of practice among the States in the regulation and control of the use of electricity in mines, as well as in its use in transportation and industrial enterprises above ground, is clearly a proper function for the national Bureau of Standards.

The personnel of the committee, as well as a brief statement of its work, was sent out to the press on August 28 from the office of the secretary of the American Mining Congress, at Denver, as follows:

STANDARDIZING ELECTRICAL EQUIPMENT IN MINING

At the Pittsburg, Pa., session of the American Mining Congress, held early in December last year, a resolution was adopted authorizing the appointment of a committee of seven persons to report back for the consideration of that organization means for bringing about the standardization of electrical equipment in mining and recommendations looking to uniformity in electrical practice in general.

The resolution, which was introduced by David B. Rushmore of the General Electric Company, Schenectady, N. Y., was as follows:

"Recommended, that a standing committee be appointed by the president of the American Mining Congress to standardize, as far as possible, and make recommendations concerning electrical practice in mining work, said committee to consist of seven members, as follows, viz: One electrical engineer, two representatives of the manufacturers of electrical equipment, two representatives of labor organizations, and two mine operators."

The following members were appointed by the Mining Congress to serve on the committee:

Dr. Edward B. Rosa, of the Bureau of Standards, Washington, D. C., chairman; David B. Rushmore, of the General Electric Company, Schenectady, N. Y., representing the manufacturers; W. A. Thomas, of the Westinghouse Company, Pittsburg, Pa., representing the manufacturers; J. R. Bent, of the Oglesby Coal Company, Oglesby, Ill., representing the mine operators; George R. Wood, of the Pittsburg Coal Company, Pittsburg, Pa., representing the mine operators; Thomas L. Lewis, president of United Mine Workers of America, Indianapolis, Ind., representing labor; James O'Connell, vice-president of American Federation of Labor, Washington, D. C., representing labor.

While the committee has been so recently organized that not a great deal of work has thus far been accomplished, it will render a preliminary report to the next session of the Mining Congress, which will be held at Goldfield, Nev., September 27 to October 2, 1909. It will then continue its work, and within the next few months it will doubtless be prepared to complete its recommendations in this important matter.

The absence of uniformity in the installation of electrical equipment in coal and precious metal mines has given rise to problems very annoying to operators and even to manufacturers, and the work of this committee will be watched with interest.

Those having any views to offer on this subject are invited to send them to Dr. Edward B. Rosa, chairman of the committee, care of the Bureau of Standards, Washington, D. C.

The committee held its first meeting in Pittsburg, September 16 and 17, and in addition to reviewing the work that had been done and outlining further work for the ensuing months, prepared a preliminary report to the approaching session of the Mining Congress, which was held in Goldfield about two weeks thereafter. This preliminary report, which was presented to the congress and printed in its proceedings, is as follows:

I. PRELIMINARY REPORT OF THE COMMITTEE ON THE STANDARDIZATION OF ELECTRICAL EQUIPMENT OF MINES

The committee on the standardization of the electrical equipment of mines, appointed in accordance with a resolution of the last session of the American Mining Congress, has had one meeting and has done a considerable amount of work on the problem assigned to it, but is not as yet prepared to offer a final report.

After examining the mining laws relative to the use of electricity of those States that have legislated on the subject, and of a number of foreign

countries where a considerable application of electricity has been made in mining, the committee has prepared a draft of a code of rules suitable for enactment into law by any state legislature. This first draft is to be submitted to representatives of other mining organizations for criticism and suggestion, and then carefully revised in the light of the suggestions received, and of the further experience of the committee. One of the members of the committee, Mr. Rushmore, is spending several months this summer in Europe studying the applications of electricity to mining, and he will doubtless obtain information of value to the committee in the final revision of its code of rules.

In addition to this formal code of rules, which may be given the force of law, governing the use of electricity in mines, the committee proposes to prepare a set of recommendations setting forth what it considers the best practice and which, if followed, would tend to reduce the danger of personal injuries due to the use of electricity in mines, reduce the liability of explosions in gaseous mines, improve the efficiency and reliability of the service and tend to make the use of electricity more satisfactory both to the operators and the mine workers. These recommendations will go farther than is possible in a set of mandatory rules.

In order that this work may be performed most effectively, the committee is gathering data concerning many of the best installations of electrical apparatus in the mines of this country and Europe, and personally examining many of them. Important experiments are being conducted by the technological branch of the United States Geological Survey to determine the condition under which explosions could be caused in gaseous mines by the breaking of incandescent electric lamps, blowing of "safety" fuses, sparking at the brushes of motors, or flashes on electric signaling wires. The effect of acid mine water on various kinds of insulated wire and cables is being investigated, with the hope of finding an insulation that will be permanently satisfactory under the severest mine conditions. The committee is glad to take advantage of the results of these experiments, in the carrying out of which one of our members (Mr. Wood) has been retained by the Geological Survey as consulting engineer. The committee invites suggestions from manufacturers, mine operators, and mine workers relative to any of the various phases of the problem which has been assigned to it, and especially any results of experience which may be of value in revising its code of rules or in making up its series of recommendations.

(Signed) E. B. ROSA,

*Chairman Committee of American Mining Congress
on the Standardization of Electric Practice in Mines.*

WASHINGTON, D. C., September 20, 1909.

In accordance with plans formulated by the committee at its Pittsburg meeting, the regulations and laws relating to the use of electricity in mines in European countries, South Africa, and New South Wales were collected and studied, the electrical installations in many mines were examined, and a considerable number of mining engineers, mine inspectors, and manufacturers of electrical machinery used in mines were consulted. No State of the Union had anything like a complete code of rules in their mining laws

respecting the use of electricity, although a careful set of rules had been prepared and submitted to the legislature of Pennsylvania a year ago. These rules were of much value to the committee and are published in this circular, although the legislature of Pennsylvania did not pass the bill. The work on a code of rules, begun in the summer, was continued, the members of the committee keeping in touch with the chairman by correspondence and assisting in the work. A second meeting of the committee was about to be called for January, 1910, when it was learned indirectly that the committee (which had been appointed by the American Mining Congress as a standing committee, and which it had been officially announced would continue its work) had been dismissed at the Goldfield meeting, and the president authorized to appoint a new committee. No notice of this action of the congress had been sent to any member of the committee and no explanation of the action of the congress has been made, nor do the published proceedings of the congress show why such action was taken.

The Bureau of Standards thus found itself with a very interesting and important piece of work partially completed, but no committee to cooperate with and no organization to which to report results. The chairman of the new committee, Samuel A. Taylor, of Pittsburg, having stated that he did not intend to take up such work as the original committee had undertaken, it has seemed best that the bureau should carry on the work to completion and publish the results. This is now being done, with the cordial support and assistance of several members of the old committee and of the manufacturers of electrical machinery used in mines, of state mine inspectors, of numerous electrical and mining engineers, and of the representatives of organized labor. A great many persons have thus been consulted in this work, and useful suggestions and criticisms have been received from a larger number than can be separately named; nevertheless, especial acknowledgment should be made to certain of those who have given us most help and encouragement. Among these are Mr. W. A. Thomas, of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.; Mr. D. B. Rushmore and Mr. Larsen, of the General Electric Company; Mr. George R. Wood, consulting electrical engineer, Pittsburg, Pa.; Mr. George Harrison, chief inspector of mines of Ohio, Columbus, Ohio; Prof. A. E. Kennelly, chairman of the standardization committee of the American Institute of Electrical Engineers, Harvard University, Cambridge, Mass.; Mr. H. M. Warren, electrical engineer, Mr. F. J. Duffey, general foreman electrical department, Mr. T. J. Williams, mine superintendent, Mr. P. J. Devers, mine superintendent, of the Delaware and Lackawanna Railway Company, Scranton, Pa.; Mr. H. N. Eavenson, chief engineer, United States Coal and Coke Company, Gary, W. Va.; Mr. L. R. Kingsland, electrical engineer, Consolidation Coal Company, Fairmont, W. Va.; and Mr. Gerald Sherman, superintendent of mine department, Copper Queen Consolidated Mining Company, Bisbee, Ariz. Mr. Thomas L. Lewis, president of the United Mine Workers of America, and Mr. James O'Connell, president of the International Association of Machinists, Washington, D. C., have also maintained an active interest in the work, and are in hearty accord with the provisions of the proposed code.

Many of the changes in practice which are recommended in the proposed rules are in the interest of better engineering, to secure more reliable service

and greater economy of operation; but very many of the changes and precautions proposed are in the interest of the mine workers, who are often exposed to unwarranted hazard where electrical installations are not properly made. The fire risk, due to live wires and electrical machinery, is such that very stringent rules have been adopted by the underwriters, acting in conjunction with various electric lighting and electrical engineering societies. The life hazard is a matter of quite as much importance; and below ground, where dampness and darkness and limited space (and sometimes explosive gases) make the difficulties and dangers greater than usual, there is need of many improvements in method and material of electrical installation, and also of a closer and more systematic inspection of such installations by the State. The best results can only be secured by cooperation between mine operators, manufacturers, and engineers, and this bureau will encourage and assist as far as possible this very important work.

Some mine operators have expressed the feeling that the work which the committee undertook and which is now being carried on by the bureau is not necessary; that the mine owners and operators can safely be left to themselves without any limitation or supervision by the State. This is perhaps true of some, particularly certain large operators who have employed able consulting engineers and who in some cases have shown exceptional enterprise and a commendable desire to make their electrical installations as safe as possible for the mine workers. But this is by no means the rule, and the records show a larger number of electrical accidents in American mines, where there has been very little official regulation or inspection of the electrical equipment, than in England and other countries, where there has been for some years very careful legal requirements and government inspections.

Still another reason for this work is that some of the States are taking a very lively interest in the question and have commissions preparing such regulations for submission to the respective state legislatures. It is very desirable that as far as possible the regulations of the several States shall be uniform. If there is no coordinating influence at work, the States are likely to have regulations that will be very different, and much confusion would therefore result to manufacturers and others who have to deal with work in more than one State. It is not improbable that in many cases such commissions would make their recommendations without consulting as carefully as we have done all the interested parties. Much good may indeed be expected from an earnest effort on the part of a national bureau which consults all the interests affected, including mine workers, mine owners, superintendents, inspectors, consulting engineers familiar with the use of electricity in mines, and the manufacturers of the electrical equipment, in which a code of regulations and restrictions is drawn up, which shall have the approval of the largest possible number, and shall be an expression, not alone of the government bureau that collects and arranges the information, but of the ablest and most experienced men of the various classes mentioned who are using electricity in carrying on mining operations.

Owing to the widely varying conditions which prevail in different mines it is impossible to formulate a series of rules or requirements that will apply to every case or that will cover every emergency. Mandatory rules must necessarily be conservative, and will not go as far in many cases as the best

practice would dictate. Hence we are preparing a set of recommendations to accompany the rules contained in this publication, and which are intended to set forth what is considered the best practice in many matters in which the formal rules, that may be given the force of law, are not complete. If the rules are made too minute or too specific, they can not be enforced without often doing injustice. But the recommendations will point out many desirable features of construction and operation that could not be required of all operators or under all conditions.

We have aimed to be very conservative in the preparation of these rules, which may become mandatory, and in many cases have been more conservative than some mine operators and experienced engineers consulted have thought necessary. While it has not been possible to draw up a proposed code of rules that meets with the unqualified approval in every detail of all those who have been consulted, we nevertheless have the assurance that the code of rules hereinafter presented represents the consensus of opinion of the great majority of those who have expressed their opinions in regard to this matter. We invite criticism and suggestion concerning the matter here submitted from any one who has had considerable experience in the use of electricity in mines, in order that we may improve the rules as much as possible in the next edition, which will be carefully revised. In the continuation of this work the Bureau of Standards will have the cooperation of the Bureau of Mines, which has recently been established. The latter Bureau will continue the experimental work begun in the Technological Branch of the Geological Survey, relative to the use of electrical apparatus in explosive atmospheres, and advantage will be taken in future editions of this report of the results of these very important experiments, as well as any other results pertinent to this work obtained by the Bureau of Mines. We believe that better construction and more careful operation will not only be of advantage to the mine workers by reducing the dangers, but will also be of advantage to the mine operators in affording more reliable service. That has proven to be the case in electricity used for lighting, for power, and for transportation, and it will surely be the same with electricity employed in the coal and metal mines.

S. W. STRATTON, *Director.*

II. PROPOSED RULES FOR THE INSTALLATION AND USE OF ELECTRICITY IN MINES

DEFINITIONS

The expression "pressure" means the difference of electrical potential between any two electrical conductors.

(a) Where the conditions of the system are such that the pressure between any two conductors, or between any conductor and the earth, at the terminals where the electricity is being used can not exceed three hundred (300) volts, this shall be deemed a low pressure system. Low pressure

(b) Where the conditions of the system are such that the pressure between any two conductors, or between any conductor and the earth, at the terminals where the electricity is being used, can exceed three hundred (300) volts, but can not exceed six hundred (600) volts, this shall be deemed a medium pressure system. Medium pressure

(c) Where the conditions of the system are such that the pressure between any two conductors, or between any conductor and the earth, at the terminals where the electricity is being used can exceed six hundred (600) volts, this shall be deemed a high pressure system. High pressure

SECTION 1.—GENERAL

Rule 1.—All electrical apparatus and conductors shall be sufficient in size and capacity¹ for the work they may be called upon to do, and so installed, operated, maintained, and safeguarded as to reduce the danger from accidental shock or fire or overheating to the minimum, and shall be of such construction and so operated that the rise in temperature caused by ordinary working will not injure the insulating materials. Size of conductors

All metallic coverings or armoring of cables, and the frames and bed plates of generators, transformers, and motors; and the metallic coverings of switches, fuses, and circuit breakers, shall be efficiently grounded.² Grounding of machine frames

¹ The table of carrying capacities of the National Electric Code should be followed where practicable. It can be obtained by addressing Mr. C. M. Goddard, secretary, Underwriters National Electric Association, 141 Milk street, Boston.

² See Note A, page 31.

Grounding of
electric circuits

Rule 2.—All alternating current systems in which the normal working pressure does not exceed the limits of medium pressure, and all three-wire direct current systems shall be grounded. Where practicable, the neutral shall be grounded.³

Pressure limits
for alternating
current machines

Rule 3.—A higher pressure than a medium pressure shall not be used for portable motors, nor for any other purpose underground except for alternating current transmission, or for application to alternating current apparatus in which the whole of the high pressure circuit is stationary. For work underground, when taking current at a pressure higher than a medium pressure, all transformers shall be of the oil insulated type and a motor shall not be of less normal rating than twenty (20) brake horsepower.

High pressure
transformers and
motors

Danger signals

All high and medium pressure lines and apparatus shall be marked at frequent intervals by the use of the word "Danger," together with a statement of the voltage, so as to indicate clearly that they are dangerous. All low-pressure power or lighting wires shall be marked with the word "Caution," together with a statement of the voltage of the line.⁴

Testing of in-
sulation

Leakage limit

Rule 4.—The insulation of each circuit or section⁵ of circuit shall be measured at least once every three months, and a record of all such measurements shall be kept at the office of the mine. If the resistance measurements show that the leakage current in any section of a lead-covered cable, or any two or three wire cable, under normal conditions of operation, may exceed 1/1000 of the maximum working current⁶ for the given conductor, the defect shall be located and repaired at once. It shall be the duty of the mine foreman, or some other responsible official designated for the purpose, to see that the tests required are regularly made, and that a portable testing set be available for the purpose.⁷

Employment of
mine electricians

Rule 5.—At every mine where electricity is used below ground, a competent mine electrician and, where necessary, an assistant mine electrician also, shall be employed, subject to the authority of the mine foreman or other responsible official. No mine shall be permitted to operate without an electrician for a continuous period exceeding thirty (30) days unless a written permit to so operate shall be obtained from the department of mines. The electrician shall have full charge of all electrical apparatus used in connection with the mine.

³ See Note B.

⁴ See Note C.

⁵ See Rule 26.

⁶ See Rule 1.

⁷ See Note D.

After the expiration of twelve (12) months from the passage of this act, no person shall be permitted to act as a mine electrician unless he shall be the holder of a certificate of competency issued by the department of mines.⁸ Licensing of mine electricians

Every person appointed to operate any electrical apparatus in connection with a mine shall be instructed in his duty by the mine foreman or electrician before taking charge of the apparatus. Instruction of electrical operators

Rule 6.—Fire buckets filled with clean, dry sand shall be kept in the mines where stationary electrical apparatus is located, ready for immediate use. Fire buckets

Rule 7.—Instructions shall be placed at the mine entrance, and in every generating, transforming, and motor house, for the resuscitation of persons suffering from electric shock. All employees operating the electrical apparatus shall be required to acquaint themselves with these instructions. Resuscitation of victims of electric shock

Every personal accident occurring in connection with the operation of the electrical equipment shall be promptly reported by the person injured, or by some other person on his behalf, to the mine foreman, and shall be recorded by him at the office of the mine. Recording of accidents

Rule 8.—A plan on a scale not smaller than 200 feet to the inch shall be kept at the mine, showing the position of all permanent electrical machinery and fixed cables or conductors in the mine, and shall be corrected as often as may be necessary to keep it as nearly as practicable up to date, and never more than six months in arrears. Plans of electric circuits of mines

Rule 9.—Any person who shall wilfully tamper with, or make any unauthorized changes in, or connections to, any part of the electrical circuits or apparatus in, or used in connection with a mine, whether such circuits are alive or not, or who shall wilfully cause any other person to come in contact with any live electrical circuits, shall be deemed guilty of a misdemeanor. Tampering with wires prohibited

Rule 10.—In any bituminous coal mine where the special rules applying to gaseous mines are not observed, precautions, such as sprinkling or other effective means, must be taken to prevent dangerous accumulation of coal dust.⁹ Alaying dust in coal mines

SECTION 2.—TRANSMISSION LINES AND CABLES

Rule 11.—Where the generating station under the control of the owner or superintendent of the mine is not within one thousand (1,000) feet of the mine entrance, a switch box or boxes efficiently Switching apparatus at mine entrance

⁸ See Note E.

⁹ See Note F.

inclosed, or a switch house, shall be provided near the mine entrance for cutting off the supply of electricity to the mine. In all mines the power for electric hoists which are regularly used for lifting miners from the workings; and in all coal mines the power for fans, must be supplied by separate feeders run from any convenient distributing point, so that power may be kept on either or both of these circuits when all other circuits in the mine are cut off.

Protection of
machine termi-
nals

Rule 12.—All terminals and live metal on machines over low pressure, below ground, shall, where practicable, be protected with insulating tape or other suitable insulating covers, or with metal covers connected to earth.

Lightning ar-
resters

Rule 13.—If the transmission lines from the generating station, or substation, to the mine entrance are overhead, they shall be properly secured to insulators and have lightning arresters at the mine entrance, if the overhead line exceeds 400 feet in length.

Minimum
height of wires on
the surface

In the case of high-voltage wires, they shall be maintained at least twenty (20) feet from the ground, except where they enter the mine or transformer station, in which case they shall be adequately protected. All medium and low voltage wires shall be maintained at least six and one-half feet above the ground at the lowest point, except where they enter the mine.

Covering of
wires and cables

Rule 14.—All high-pressure wires in underground roadways shall be in the form of lead-covered cables, which may be either armored or unarmored. The insulation of these cables must be non-hygroscopic and as nearly acid proof as possible, so that a defect in the lead sheath will not give rise to an immediate breakdown of the insulation.¹⁰

In nongaseous sections of mines, medium or low pressure wires may be bare. If insulated, they must be covered with high-class insulation that is as nearly moisture and acid proof as possible. All high and medium pressure wires, unless metal covered, must be adequately protected where there is danger of men or animals coming into contact with them.

Protection of
cable terminals

Rule 15.—The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances shall be properly protected and finished off so that moisture can not creep along the insulating material, or so that the insulating material, if of an oily nature, can not leak out of the cable.

Joints

Rule 16.—All joints must be electrically efficient, mechanically strong, and where practicable should be soldered. All joints,

¹⁰ See Note G.

except in trolley wires, should be taped or otherwise suitably insulated to protect them from corrosion.¹¹

Rule 17.—All cables used in shafts must be highly insulated and substantially fixed. Shaft cables not capable of sustaining their own weight shall be properly supported at intervals, according to the weight of the cable. Where the cables are not completely boxed in and protected from falling material, space shall be left between them and the side of the shaft, so that they may yield when struck, and thus lessen the blow given by the falling material. Shaft cables

Rule 18.—Where the cables in main haulage roads, where persons are hauled into or out of the mines, can not be kept at least 18 inches from any part of the car, they shall be specially protected. Protection of cables in roadways

Cables and wires, unless provided with metallic coverings, shall not be fixed to walls or timbers by means of non-insulating fastenings. Supporting of wires and cables

Metal covered or any multiple conductor cables underground, when suspended, shall be supported flexibly in such a manner as to allow of their readily breaking away when struck before the cables themselves can be seriously damaged.

Where main or other roads are being repaired, or where blasting is being done, temporary protection must be used, so that the cables are protected from damage. Protection of cables while blasting

Rule 19.—Trailing cables for portable motors shall be especially flexible, heavily insulated, and protected with extra stout braiding, or other equally effective covering. Trailing cables

Rule 20.—The twin trailing cables, supplying power to coal cutter motors, shall be divided at the motors, but only for such a length as is necessary for making the connection to the motor, and the twin cable, with its outer covering complete, shall be securely held by a suitable clamp on the frame of the motor, in such a manner as to protect the trailing cable from injury, and to prevent any mechanical strain being borne by the terminals making electrical connection with the motor. Connection of trailing cable to motor

Rule 21.—In the event of the trailing cable in service breaking down or being damaged, or of its inflicting a shock upon any person, it shall at once be put out of service, and shall not be used again until it has been repaired and tested by the mine electrician or assistant mine electrician. Operation of trailing cables

The trailing cable shall be kept disconnected from the machine while it is being loaded upon or unloaded from the truck, unless electric power is necessary for such loading or unloading.

¹¹ See Note H.

Location of
wires in road-
ways

Rule 22.—In underground roads, the trolley wires shall be placed as close to the side as practicable, and in a straight line, and securely supported at frequent intervals. In all roads where it is necessary for men to travel on foot, all wires, except signal wires, must be placed on the same side of the roadway. Signal wires should where practicable be placed on the opposite side of the roadway from other wires.

Protection and
illumination of
wires at crossings

At all landings, turn-outs, partings, or crossings, or other places where it is necessary for men to pass near the wires, a suitable protection shall be placed around the wires, or the pressure must be cut off when such places are used for traveling on foot. Sufficient illumination shall be provided at all points where men are liable to come in contact with power wires.

Automatic trol-
ley switches and
danger signals

Every branch trolley shall be fitted with an automatic trolley switch, or section insulator and line switch, or some other device that will allow the pressure to be cut off from such trolley when not actually in use.¹² Danger signals, consisting of no fewer than two red lights in parallel, and as many in series as may be necessary, shall be connected at suitable intervals to all branch trolley circuits to indicate when the current is on. A notice shall be posted at the entrance to all roadways carrying exposed power wires, warning persons against the dangers of carelessly carrying metal tools such as drills, picks, etc., which may come in contact with the wires.

Erection of
lighting and sig-
nal wires

Rule 23.—Small wires for lighting or signal circuits shall either be conveyed in pipes or casings, or they may be suspended from porcelain or glass insulators or securely tied to them, so that they do not touch any timbering, coal, or metal. On no account shall staples be used. If metallic pipes are used, they must be grounded, and if not electrically continuous, every section must be grounded. If separate uncased wires are used, they shall be kept at least three (3) inches apart, and not brought together, except at lamps or fittings.

SECTION 3.—SWITCHES, FUSES, AND CIRCUIT BREAKERS

Adjustment
and replacing of
fuses and cir-
cuit breakers

Rule 24.—Fuses and automatic circuit breakers should be so constructed or adjusted as to open the circuit when the current through them exceeds, by 100 per cent, the working current in the case of motors, or the permissible current of the cables which they protect. Fuses shall be stamped or marked, or shall have a label attached indicating the current at which they are

¹² See Note I.

intended to fuse, or, where fuse wire is used, each coil shall be so stamped and labeled. Fuses shall be adjusted or replaced only by a competent person, authorized by the mine foreman.

Rule 25.—All switches, circuit breakers, and fuses must have bases of marble, slate, or porcelain, or other suitable incombustible material, free from metallic veins, and shall be placed in as dry a situation as practicable. Construction and location of switches, fuse blocks, etc.

Rule 26.—Wherever branch electric circuits leave a main or secondary feeder, switches shall be provided for disconnecting the branch line from the supply line, and all main and distributing feeders shall be provided with sectionalizing switches at distances not exceeding one mile.¹³ Sectionalizing switches and branch cut-outs

All circuits that are to be made or broken underground shall be fitted with proper switches. If connection is made to the supply line by means of hooks or other temporary connections, the switch must be open when such connection is made or broken. Connection of branch circuits to supply line

SECTION 4.—MOTORS

Rule 27.—Every underground motor, together with its starting resistance, shall be protected by a fuse or circuit-breaking device, in accordance with rule 23, and by switches capable of entirely cutting off the pressure. The switches shall be placed in a convenient position near the motor. Auxiliary appliances for motor

Rule 28.—Where unarmored cables or wires pass through metal frames or into boxes or motor casings, the holes shall, where practicable, be substantially bushed with insulating collars. Bushing for cable boxes, etc.

Rule 29.—No person shall be permitted to take charge of an electric coal-cutting machine in a mine who is not a competent person, capable of determining the safety of the roof and sides and of detecting the presence of explosive gas. Precautions in the operation of coal cutters

In order that the roof may be carefully examined, a coal-cutter motor shall not be kept continuously in operation for a length of time exceeding half an hour, unless otherwise specified in writing by the mine foreman.

Rule 30.—The person in charge of a coal-cutting or drilling machine shall not leave the machine while it is working, and shall see that the pressure is cut off from the trailing cables before leaving the working place.

Rule 31.—Electricity from light and power circuits shall not be used for firing shots in a mine except where the electrical connection to such light or power circuit is made within an inclosed Shot-firing regulations

¹³See Note J.

switch room, which shall be kept securely locked and shall be accessible only to the authorized shot firer. If electricity from light or power cables is used for firing shots in a mine, no shots shall be fired until all the men are out of the mine.

Special precautions must be taken to prevent accidental contact between shot-firing cables or wires and power and lighting cables.

Only persons authorized in writing by the mine foreman or superintendent are permitted to fire shots electrically in a mine.

Rule 32.—All apparatus used for firing shots electrically shall be of a type approved by the inspector for the conditions under which it is to be used.

Rule 33.—Where battery or magneto exploders are used, they shall be inclosed in a suitably constructed box, fitted with a removable connecting plug or key without which the circuit can not be closed. This plug or key shall be detached when not required for firing and shall not under any conditions pass from the personal custody of the shot firer while on duty. Exploders shall be frequently tested by the shot firer to insure that they give the necessary pressure and current.

The exploder shall not be connected to the shot-firing cable until all other steps preparatory to the firing of the shot have been completed and all persons have removed to a place of safety.

Immediately after the firing of the shot, the firing cable shall be disconnected from the exploder, and no person shall approach a shot that has been attempted to be fired by electricity and has failed to explode until the firing cable has been so disconnected and an interval of five minutes has elapsed since the last attempt to fire the shot.

Rule 34.—All proper precautions shall be taken to prevent electric wires from coming in contact with other electrical conductors, whether insulated or not.

Construction of
signal systems

Bells, wires, insulators, contact makers, and other apparatus used for electrical signaling in connection with the working of a mine shall be of substantial and reliable construction, and shall be erected in such a manner as to reduce the liability to failures or false signals to the minimum.

Telephone sys-
tems. When re-
quired. How in-
stalled

Rule 35.—All coal mines from which exit is by shaft only, and all others in which the working places extend more than one mile from a place of exit, shall be provided with telephone systems, provided the number of men employed at any one

time on the regular working force exceeds twenty-five.¹⁴ The system shall be of approved construction, and of such extent that no working place shall be at a greater distance than three-fourths mile from a telephone, and all places where there are permanent attendants shall be provided with telephones. If more than one hundred men are employed at any one time on the regular working force inside the mine, the telephone lines shall, if possible, be introduced through drill holes so that falls of earth and explosions will be less likely to interrupt the working of the telephone system. All main telephone cables shall be insulated with water-proof insulation, and, unless run through metal pipes or casings, they shall be protected by a continuous lead sheath.

SECTION 5.—SPECIAL RULES GOVERNING THE USE OF ELECTRICITY IN GASEOUS MINES

Rule 36.—In all mines which generate any appreciable quantity of explosive gas and in which electricity is employed below ground, every working place shall be examined daily by an authorized fire boss before any men are permitted to go to work in the mine, and if explosive gas is found in any part of the mine in sufficient quantities to permit its detection by an approved type of safety lamp, the test being made under normal conditions of ventilation, no electrical pressure shall be permitted on any circuits for a period of twenty-four hours in that part of the mine in which gas is found or in any other part of the mine in the return air course from said gaseous part.¹⁵

Rule 37.—If any mine generates a sufficient quantity of explosive gas to render necessary the use of locked safety lamps in any part or parts of the mine, those parts of the mine in which locked safety lamps are necessary shall be subject to the following rules in addition to those provided for other mines.

Rule 38.—In any part of a mine in which locked safety lamps are necessary, if, for any reason, the normal ventilation is stopped for a period exceeding fifteen minutes, the pressure shall be switched off from all direct-current motors in the same air course, which are not provided with explosion proof casings, except such motors as may be used for driving the ventilating fans or removing men from the mine, and the pressure shall not again be switched on until normal ventilation has been resumed and tests have been made to show that the mine is free from gas.

Stoppage of ventilation

¹⁴ See Note K.

¹⁵ See Note L.

High pressure
prohibited

Rule 39.—No pressure higher than a medium pressure shall be used, and no bare wires other than signal wires shall be permitted.

Mine electrician
required to
be on duty

Rule 40.—The mine electrician or assistant mine electrician shall be on duty in the mine at all times when the electric power being used for the production of coal in a gaseous part of a mine exceeds twenty-five (25) horsepower.

Main cables,
location of

Rule 41.—Main cables shall be taken into the mine only by way of the intake air way, or through separate openings provided especially for the purpose, and so situated as always to be free from explosive gas.

Operation of
trailing cables

Rule 42.—Each trailing cable shall be examined daily by the machine boss for abrasions and other defects.

The machine man shall also be required to observe carefully the trailing cable while in use, in order to detect defects, and in the event of any defect becoming apparent, notice of the same shall at once be given to the mine electrician or assistant mine electrician.

Switches

Rule 43.—The use of hooks or other makeshifts for making or breaking a circuit is forbidden, and all switches, circuit breakers, and fuses, shall be inclosed in explosion-proof boxes or break under oil.

Drying motors

Rule 44.—Where the insulation of a motor is found to become damp during a stoppage, suitable steps shall be taken to insure that the insulation shall be dry before the working of the motor is resumed.

Explosion-proof
casings required
on direct-current
motors

Rule 45.—All direct-current motors, unless placed in rooms separately ventilated by intake air, shall have all their current-carrying parts, switches, starters, terminals, fuses, and connections completely inclosed in explosion-proof casings,¹⁶ which shall be of sufficient strength to resist the force of an internal explosion, and which shall be provided with special outlets so designed that the escaping gases shall be cooled to such an extent that they can not communicate the explosion to the outer atmosphere. Such inclosures shall not be opened except by an authorized person, and then only when the pressure is switched off. The pressure shall not be switched on or off while the inclosures are open. All alternating current motors shall be operated only by inclosed, oil-break switches.

Oil switches re-
quired with A. C.
motors

Apparatus for
testing gas must
be provided for

Rule 46.—A safety lamp or other suitable apparatus for the detection of explosive gas shall be provided for the use of the

¹⁶ See Note M.

attendant of all electrical apparatus underground, and should any indication of explosive gas appear on the flame of the lamp, or other apparatus used, the person in charge shall immediately stop the machine, cut off the pressure at the nearest switch, and report the matter to the mine foreman, who shall see that, as soon as practicable, the pressure shall be cut off from the wires or cables leading to that part of the mine. The pressure shall not again be switched on until at least twenty-four hours have elapsed since the last appearance of gas.

Rule 47.—Before an electric coal-cutting machine is brought within twenty (20) yards of the working face in a gaseous part of a mine, the machine man shall make an inspection for gas in the place where the machine is to work, unless such examination is then made by some other competent person authorized or appointed for that purpose by the mine foreman. If any explosive gas is found in the place, the machine shall not enter therein.

No coal-cutting machine shall be continued in operation for a longer period than half an hour, unless otherwise specified in writing by the mine foreman, without an examination being made for gas, as described above, and if gas is found, the current shall be switched off the machine at once, and the trailing cable shall forthwith be disconnected from the feed wire.

The person finding gas shall at once erect a danger signal to warn persons against entering the place. The trailing cable shall be removed from such place, and shall not be brought back, nor shall the machine be again started until the fire boss, or a person duly authorized by the mine foreman, has examined it and has pronounced it free from gas, and has removed the danger board.

The person finding gas shall forthwith report the same to the mine foreman, and at the end of the shift he shall make and sign a written report in a book kept at the mine for the purpose.

Rule 48.—If any sparks or arcs appear outside the casing of any inclosed motor, or about the cables or rails, the machine shall be stopped, and shall not be worked again until the defect has been repaired, and the occurrence shall be reported to the mine foreman or assistant mine foreman.

Rule 49.—All inclosed motors used underground shall be opened and inspected at least once a week by the mine electrician or his assistant, and, where necessary, shall then be cleaned and repaired. Inclosed switches shall be opened and inspected at least once every month.

Trolley wires
prohibited

Rule 50.—Electric haulage on the trolley wire system shall not be allowed in any part of a mine where locked safety lamps are necessary. If storage battery locomotives are used in such places, the rules applying to motors shall also be deemed to apply to the boxes containing the cells.

Storage cells
must be inclosed

Electric light-
ing

Rule 51.—In any part of a mine where there is danger of igniting gas or coal dust, electric lamps, if installed, must be of the inclosed vacuum type, and they shall be inclosed by gas-tight fittings of strong glass and shall have no flexible cord connections. Electric lamps shall be replaced only by an authorized person.

In all machine rooms and other places in gaseous mines where the failure of electric light is likely to cause danger, some safety lamps or other proper lights, not fewer than the number to be prescribed for such place by the inspector, shall be kept for use in the event of such failure.

Electric relight-
ing of safety lamps

Rule 52.—Wherever safety lamps are to be lighted underground by electricity, the mine foreman shall select a suitable station or stations not in the return airway, and where there is not likely to be any accumulation of explosive gas, and no electric relighting apparatus shall be used in any other place. All electric relighting apparatus shall be securely locked, and shall not be available for use except by persons authorized by the mine foreman to relight safety lamps, and such persons shall examine all safety lamps brought for relighting before they are reissued.

Limiting pres-
sure on signal cir-
cuits

Rule 53.—In any part of a mine where safety lamps are necessary the pressure used for signaling shall not exceed 50 volts, and bare wires shall not be used for such purposes except in haulage roads.

Carrying ca-
pacity of conduct-
ors

Rule 54.—All conductors shall have a rated carrying capacity in accordance with the requirements of the National Electric Code.

SECTION 6.—THE INSPECTION OF THE ELECTRICAL EQUIPMENT OF MINES

Appointment of
Examining Board

The governor shall appoint, within three months after the passage of this act, three (3) citizens of this Commonwealth of good repute, to be known as the Examining Board for Electrical Mine Inspectors and Mine Electricians, whose duty it shall be to examine applicants for the office of electrical inspector of mines of this Commonwealth and to examine persons who desire to receive certificates of competency as mine electricians. The chief of the department of mines shall be ex officio chairman of this Board,

Personnel of
Board

and the other two members shall be, one a mine superintendent, and one an electrical engineer. They shall be at least 30 years of age, and shall have had at least five years' experience in the practice of their respective professions. The chairman of this board shall receive no other compensation than his salary as chief of the department of mines. The other two members of the Examining Board shall each receive the sum of ten (\$10) dollars a day for each day actually employed in discharging their duties according to the provisions of this act and all necessary expenses incurred in performing the duties imposed upon them by this act. Any vacancy that may occur in the membership of the Examining Board shall be filled by the governor according to the provisions of this act.

Compensation

Vacancies, how filled

The Board after being duly organized shall, before proceeding with its duties, go before any proper officer authorized to administer oaths and each member shall be duly sworn to faithfully perform the duties of his office without fear or favor.

Members of Board to be sworn

The oaths of the members of the Examining Board shall be kept on file in the office of the department of mines as public documents.¹⁷

The Examining Board shall be convened by the chief of the department of mines at such time as circumstances may require, for the purpose of examining applicants for the office of electrical inspector of mines, or for preparing questions and formulating rules for conducting examinations, or for performing any other duties made necessary by the provisions of this act. The Examining Board shall also meet regularly once each year, and oftener if necessary, for the purpose of examining applicants for the certificate of competency as mine electrician.

Meetings of Board

Every examination shall be publicly advertised throughout the mining district for a period of at least thirty (30) days prior to the date of the examination, and the time and place of the examination and the conditions of eligibility shall be fully stated in the advertisement.

Examinations to be advertised

¹⁷ The following form of oath is suggested:

We, the undersigned, do solemnly swear (or affirm) that we will perform, to the best of our ability, the duties of examiners of applicants for appointment to the office of electrical inspector of mines, and of persons desiring to secure certificate of competency as mine electricians, and that in judging such applicants we will be governed solely by the evidence of their fitness to perform the duties of electrical inspector of mines and of mine electrician, in their respective classes, as imposed by this act, and that we will refuse to certify all who fail to show proper evidence of their fitness for such duties.

**Qualifications
of candidates for
office of electrical
inspector**

All applicants for appointment to the position of electrical inspector of mines shall certify to the Examining Board that they are citizens of the State of ; that they are not pecuniarily interested in any of the mines of the State; that they are men of personal integrity, of temperate habits, and of good repute; that they are in good physical condition; and that they are between the ages of thirty (30) and forty-five (45) years. Provided, however, that any person who has served as electrical inspector under this act before reaching the age of forty-five (45) years shall be eligible to reappointment at the discretion of the Examining Board.

Applicants must further show that they have had at least five years of practical experience in the operation of electrical apparatus devoted to power purposes, at least two years of which must have been in connection with the electrical equipment of mines.

**Nature of ex-
amination**

The examination shall be in writing and shall be of such a nature as to show that the applicant possesses sufficient theoretical and general practical knowledge of the application of electricity to mining, of the dangers attending its use, and the safeguards that should be employed. Each applicant must also show that he possesses a full knowledge of the code of the Underwriter's National Electrical Association, of the rules of the American Institute of Electrical Engineers, and of the rules governing the use of electricity in mines as prescribed in this act.

**Grading of ap-
plicants**

The Examining Board shall grade each applicant according to his merit. In determining the grade, the previous experience and record of service of the applicant together shall have equal weight with the written examination, and only those who receive a grade as high or higher than that previously determined upon by the board shall be eligible to appointment. The examination sheets of all applicants, together with the complete list of questions and their correct solutions, shall be kept on file in the office of the department of mines as public documents. The Examining Board shall certify to the governor and to the department of mines the name and grade of all successful candidates and shall issue to every candidate a statement of the result of his examination.

**Appointment of
inspectors, num-
ber, etc.**

The governor shall, from the names certified to him by the Examining Board, commission as many electrical inspectors as the conditions of the service may require, but at least one electrical inspector must be appointed for each five inspection districts of the State. Provided, that if in any district the regular inspector

of mines is also a qualified electrical inspector, such district need not be counted in determining the number of electrical inspectors necessary. When appointments are made, those persons standing highest in percentage on the examination shall be given preference over those of lower percentage. Provided, that any person who has not been certified as hereinabove provided within a period of ten years, shall not be deemed eligible for appointment or reappointment to the office of electrical inspector of mines until he shall have been again examined and certified by the Examining Board according to the foregoing provisions of this act.

All appointments to the office of electrical inspector of mines shall be for a full term of six years, but in case of a vacancy the governor may commission for the unexpired term the person having the highest grade on the certified list.

Electrical inspectors on first appointment shall receive a salary of three thousand (\$3000) dollars per year, which shall be increased to thirty-five hundred (\$3500) dollars per year after the inspector has served for six years.¹⁸ Each electrical inspector may incur traveling expenses and such other expenses as may be necessary for the proper discharge of his duties under this act, which shall be paid quarterly by state treasurer on warrant of state auditor issued upon presentation of vouchers sworn to by the inspector and approved by the chief of the department of mines.

The electrical inspector shall inspect the electrical equipment used in, or in connection with, all of the mines within his jurisdiction as often as possible. Within five (5) days after completing the inspection of a mine, the inspector shall prepare a printed report setting forth fully the condition of the electrical equipment of said mine, the copy of this report shall be sent to the office of the department of mines, where it shall be kept on file as a public document, and another copy shall be sent immediately to the superintendent of the mine to be posted by him in a conspicuous place near the workings.

If the inspector discovers any violation of any of the provisions of this act, or any conditions which, in his opinion, may be contrary to the spirit of this act, he shall at once notify the super-

¹⁸ In some of the more important coal mining States the responsibilities of the electrical inspector of mines are so great that the salaries here suggested appear to be very moderate. In other States, as, for example, in the metal mining States or those States in which the coal mining industry is not of great magnitude, a smaller salary would be indicated.

intendent or manager of the mine in which such condition is discovered and order the immediate removal of the defect. If the superintendent or manager fails to remove at once such condition,¹⁹ the inspector shall immediately report the matter to the chief of the department of mines, who shall promptly designate two other inspectors who shall accompany said electrical inspector to the mine wherein said dangerous condition is alleged to exist. If after a full investigation the inspectors agree that the condition is one of grave danger, they shall direct the superintendent of the mine in writing to remove the dangerous condition immediately, and if the superintendent fails to do so, the inspectors shall at once apply to the proper court for a writ of injunction to enjoin the immediate suspension of all work in or about any part of the mine which the inspectors believe to be jeopardized by the dangerous condition. Whereupon the court shall proceed immediately to hear the case, and if the cause appear to be sufficient he shall issue a writ of injunction restraining the working of said mine until it can be shown to the satisfaction of the court that the provisions of this act have been complied with.

If the court shall sustain the decision of the inspectors, the costs of the proceeding shall be paid by the owner or agent operating the mine, but if the court shall not sustain the decision of the inspectors, the costs shall be paid by the county.

Electrical in-
spector subordi-
nate to chief of
department of
mines

The electrical inspector shall work under the direction of the chief of the department of mines, and shall perform such duties and make such reports from time to time as he may direct.

Powers of elec-
trical inspectors

If at any time the electrical inspector shall discover any condition of so grave a character that, in his opinion, any delay might be disastrous to life, he shall have the power to withdraw temporarily all persons from such dangerous place until the foregoing provisions of this section can be carried out.

¹⁹ In a proposed code recently prepared by the department of mines of Pennsylvania and presented to the state legislature, the procedure is briefly as follows:

In case of disagreement between inspector and mine owner or operator, the owner or operator shall appeal to the chief of the department of mines, who then appoints two other inspectors to accompany the inspector of the district to make a further examination into the matter in dispute. If the inspectors agree their decision shall be final unless the owner or operator shall appeal within seven days to the proper court. The court must then appoint three persons as referees to investigate the matter, and if they sustain the decision of the inspectors, their decision shall be final unless a bill of exception is filed by the owner or operator within ten days, in which case the court shall proceed at once to hear the case, and his decision shall be final and conclusive.

The electrical inspector shall have the right to enter any mine within his jurisdiction at any time for the purpose of making examinations or obtaining information. In case of accident, resulting directly or indirectly from the use of electrical apparatus in or about the mine, the electrical inspector shall be required to make a full and complete investigation into the nature and cause of the accident, and to enable him to do this he shall have power to summon witnesses and administer oaths. He shall make a full report of every such investigation to the chief of the department of mines.

Additional powers and duties of electrical inspectors

When written charges of incompetency or gross neglect of duty, or malfeasance in office, shall be brought against any electrical inspector, and signed by not less than 15 coal miners, or by one or more mine owners or operators (and accompanied by a bond in the sum of five hundred (\$500) dollars, payable to the State and signed by two or more responsible freeholders, and conditioned for the payment of all costs and expenses arising from the investigation of such charges) the governor shall convene a board of examiners to investigate the case, which board shall consist of three members, one of whom shall be a member of the electrical inspector's examining board, one a mining engineer, and the third the attorney-general of the State or a presiding judge of the district court, said board to be convened at such time and place as the governor may deem best, giving ten days' notice to the inspector against whom the charges are made, and also the persons who have made the charges. The board when so convened, and having been first duly sworn truly to try and decide the charges made, shall summon any witnesses desired by either party to the case, and examine them on oath which may be administered by any member of the board, and depositions may be read on such examination as in other cases; and the board shall examine fully into the charges and report the result of the investigation to the governor. If the board shall sustain the charges made, the governor shall at once declare the office of the said electrical inspector vacant, and shall proceed to fill the same in accordance with the provisions of this act, and the costs of said investigation shall be paid by the county. If, however, the charges shall not be sustained, the said electrical inspector shall stand exonerated, and the costs of the examination shall be paid by the persons signing the bond.

Trial of electrical inspector

Costs of trial

**Qualifications
of candidates for
post of mine elec-
trician**

Applicants for the mine electricians' certificate of competency shall be required to give satisfactory evidence that they are at least 21 years of age, that they are of temperate habits and of good repute, and that they are in good physical condition. They must further show that they have had at least two years' practical experience either as assistant mine electrician or in the operation of electrical systems devoted to power purposes, in which case their experience must include both wiring and the operation and repair of electric motors. They must give evidence that they possess a practical knowledge of electric wiring, the making of joints, bonding of tracks, and testing for faults in wires, cables, and motors. Also, that they have a due appreciation of the dangers attendant upon the use of electricity in mines, and a knowledge of the proper safeguards. They must show also that they possess a sufficient knowledge of the rules of the American Institute of Electrical Engineers, and of the rules and regulations provided by law for governing the use of electricity in mines in the State of

**Duties of mine
superintendent,
etc.**

It shall be the duty of the mine superintendent, mine foreman, or other official in responsible charge of the mine at the time of any serious accident, at once to give notice of such accident to the inspector of the district in which the accident occurred.

Penalties

Any person who shall violate any of the provisions of this act shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punished by a fine not exceeding one hundred (\$100) dollars, or by imprisonment for a term not exceeding three months, or by both such fine and imprisonment, at the discretion of the court.

Any mine owner, superintendent, mine foreman or mine electrician who shall wilfully permit any violation of any of the provisions of this act shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punished by a fine not exceeding two hundred (\$200) dollars, or by imprisonment for a term not exceeding six months, or by both such fine and imprisonment, at the discretion of the court.

**Liability of em-
ployers**

If any employee shall receive any injury, occasioned by the violation of any of the provisions of this act by the owners, operators, or any responsible employee of said owners or operators, a right of action shall accrue to the injured party against said owner or operator, for any injuries he may have sustained thereby. And in case of loss of life by reason of such violation aforesaid, a right of action shall accrue to the widow or lineal heirs of the deceased for the recovery of damages.

III. SOME EXPLANATORY STATEMENTS IN REGARD TO THE PROPOSED CODE OF RULES GOVERNING THE USE OF ELECTRICITY IN MINES

In the accompanying code there are a number of proposed rules in regard to which there appears to be considerable diversity of opinion. It has seemed wise therefore to accompany these proposed rules with a few explanatory notes setting forth the principal considerations that have led to the adoption of certain of the proposed rules about which there may be some question.

NOTE A

Rule 1 (second paragraph).—This rule requires that the frames and bed-plates of generators, motors, and transformers, and the metallic coverings of cables, switches, etc., shall be grounded.

Four objections are usually brought against grounding as herein required, viz:

- (1) It produces greater strain on the insulation.
- (2) A single fault in the insulation requires the shutting down of the machine or cable.
- (3) Such a fault may develop a short circuit and the flash which results may ignite gas, should the latter be present.
- (4) Difficulty is often experienced in making a good ground, especially for coal-cutter motors.

The first of these objections can be justified only on the ground of economy in the initial installation. It is true that a somewhat cheaper machine can be built where the insulation strains can be kept low, but in the case of low or medium voltage machines for mining work the severe mechanical strains that are put on the insulation due to severe overloads, mechanical shocks, etc., require that the insulation be of such strength and quality that the additional voltage strain that would be caused by grounding the frame would be of relatively small consequence. The difference in cost would therefore be of such slight importance that it would be hardly worthy of consideration in comparison with the much more important question of safety.

As regards the second objection, that a single fault in the insulation makes it necessary to shut down the machine, it must be said that this is true only in case one point of the electric circuit is grounded, and even then it can hardly be regarded as a disadvantage. A machine which has developed a fault in its insulation should never be continued in operation in a mine even though such operation may be possible. Any machine that has developed a fault in its insulation is obviously more likely to develop another than one in which trouble has never occurred, because the appearance of the first fault often indicates a bad condition of the insulation as a whole.

Hence it is more dangerous to operate a machine that is grounded through defective insulation than to operate one in which the frame is intentionally connected to earth. Moreover, either through overlooking the defect, or owing to the inevitable tendency of the operator to keep the machine in operation, even after the first defect is discovered, this condition of greater danger would frequently arise.

The third objection mentioned carries practically no weight for the reason that the rules prohibit the operation of electric machines where gas in explosive quantities is present, and the possibility of a short circuit developing during the interval between the appearance of gas and the shutting down of the machine is very remote.

The last objection is not serious since the ground wire need not be of large current carrying capacity, hence a small flexible wire can be run to any convenient ground plate or other suitable ground, either back along the trailing cable or separately as the case may require. Since this wire is not alive its presence can not be regarded as materially objectionable and the question of insulation does not arise at all.

On the other hand we have the unquestionable fact, supported by numerous authentic records, that persons have frequently been killed by coming in contact with the ungrounded frame of a motor or coal cutter which had accidentally become alive even from a lower stage circuit; whereas such accidents are rendered absolutely impossible by the thorough grounding of the frames of such machines.

It would seem therefore that the doubtful advantage of ungrounded machine frames can hardly be regarded as comparable with the positive safety from shock assured by the thorough grounding of such machines.

Grounding of machine frames, cable sheaths, etc., is required by law in Great Britain, Cape of Good Hope, and New South Wales.

NOTE B

The grounding of three-wire direct current systems and all alternating current systems of low or medium voltage is deemed of great importance as a measure of safety. The large number of deaths from electric shock from low and medium voltage circuits has proven beyond a doubt that the danger even from low voltage circuits is serious and should be guarded against wherever possible. Three-wire systems are rarely installed in mines for lower than medium voltages, and since the grounding of the neutral of such a system reduces the normal working pressure between either line and ground to one-half what it would if one side were grounded, it is desirable that the neutral point be grounded wherever possible.

In alternating current systems the danger from shock arises from two sources, viz, from the normal working pressure of the circuit, and in the case of secondary circuits, from the high pressure of the primary circuit due to accidental contact between primary and secondary system. Danger from the latter source is eliminated by grounding any point of the secondary system. If one side of the secondary be grounded, however, there would still remain the danger of shock from the normal working pressure of the secondary circuit, while if the neutral or middle point of the secondary winding of the transformer be grounded, a person standing on the ground and

touching either wire would receive only half of the normal working pressure between lines in the case of a single-phase system. Here, again, therefore, the neutral should be grounded wherever possible. Most companies are now prepared to supply standard types of transformers, in which the neutral can readily be grounded when working at pressures of 220 or 440 volts, so that this presents no difficulty. In three-phase systems two cases have to be considered, viz, the Δ and Y connected secondaries. In the latter the common connection of the three phases is commonly called the neutral and this point should always be grounded, since by so doing the voltage between any line and ground is reduced to about 58 per cent of what it would be if one line were grounded. In case the secondary is connected in Δ there is no neutral point as in the case of the Y connection. In this case the neutral point of one phase, and one only, should always be grounded, as in this case the pressure between two of the lines and ground is reduced to one-half of the normal working pressure between lines, and that between the third line and ground is reduced to about 86 per cent of the normal line voltage. It is apparent, therefore, that grounding a proper neutral point on any system greatly reduces the danger of shock. It may be noted that the delta-connected system gives a somewhat less satisfactory condition in this respect, but inasmuch as this connection is sometimes preferable in practical operation, it does not seem desirable to prohibit its use.

NOTE C

Rule 3.—The prohibition of pressures higher than 600 volts on portable motors and the moving parts of machines is justified by the fact that with these high voltages the question of insulation becomes a very important one and the necessity for maintaining thorough insulation is imperative. It has been demonstrated by experience that the insulation of moving armature coils and of flexible trailing cables, especially the latter, is much more difficult to maintain than in the case of stationary armatures and fixed cables. Moreover, portable motors and cables require much more handling than stationary motors and hence the liability to shock becomes greater.

In the excessively damp atmosphere that prevails in many mines the use of an air blast for cooling transformers seems certain to give rise to serious insulation troubles. Oil insulated, oil or water-cooled transformers have demonstrated their reliability and comparative safety under all conditions of service, and it is therefore believed that a maximum degree of safety will result from their use.

The limitation of high-voltage motors to 20 horsepower or over is advisable for several reasons: In the first place, it is very difficult to provide ample insulation for the coils in the small space available in motors of less than 20 horsepower without making an unduly large and expensive machine; and further, since small machines usually receive less care and attention than large machines, trouble is more likely to develop. Again, the use of high voltage is desirable only for the sake of securing economy of copper in the transmission line, and its importance therefore depends on the amount of power to be transmitted. In the case of very small powers, the total charge for copper with medium voltage would be small and hence the saving

by the use of high voltage would not be sufficient to justify the increased hazard which must accompany its use, and its use in such cases should therefore be discouraged.

It seems advisable to make a distinction between the danger signals to be used on high and medium voltage systems for the reason that men, as a rule, have a tendency to disregard danger signals if they are too common, and this would be especially true if the same signals are used on the high-voltage circuits as are used on the low-potential circuits. By making a distinction between the two classes, the high-voltage circuits at least, which are admittedly the most dangerous, are more likely to be avoided.

It has been argued that the tendency of men to disregard danger signals is so great that it is useless to provide them in any case. It can not be denied, however, that there are many men who desire to avoid danger and would do so if they were warned of its presence, and in justice to such it appears that the least that can be done is to point out that the wires are dangerous, and also as near as may be, indicate the degree of the danger.

Not a few persons consulted have opposed the provision requiring that low-pressure circuits be marked with the word "Caution." Our records show, however, that in the aggregate a large number of persons have been killed by coming in contact with low-voltage wires, and we believe that some sort of warning is necessary.

NOTE D

Rule 4.—In the matter of leakage, it seems necessary to make a distinction between cables of two or more wires, or those with metallic sheaths, and those wires that may give rise to leakage over exposed surfaces. In the former case any leakage that may exist must of necessity pass through the insulation, and a relatively small amount of leakage would indicate a defective condition of the insulation which might at any time develop serious consequences. On the other hand, in the case of wires which depend on their supports for insulation, such as trolley wires, there is the possibility of leakage over exposed surfaces, and in general owing to accumulations of damp coal dust and dirt, which may contain considerable acid, the leakage will be much greater. The leakage current will, as a rule, be distributed over a great many insulators, and further since it indicates, as a rule, only a temporary condition that can be readily removed by cleaning the insulators, it is not to be regarded as being as serious as leakage from cables, and hence much larger leakage may be permitted in such cases.

NOTE E

Rule 5. Examination of mine electricians.—The post of mine electrician is one of considerable importance, since it has much to do not only with the economy and reliability of operation of the electrical system, but also with the safety of the miners. Great care should therefore be exercised in choosing a man for this place.

We believe that mine electricians should be required to pass an examination along the lines indicated in section 6 of the proposed code, for reasons which will appear from a careful consideration of the qualifications which

such persons ought to possess. A mine electrician must be, among other things, a person capable of exercising sound judgment. In order to do this, he must have had ample experience, since no inexperienced person can judge soundly in regard to technical matters. He must also have a thorough knowledge of the state laws governing the use of electricity in mines, in order that he may know when the laws are being complied with. An examining board, properly constituted, can determine with certainty in regard to the two latter of these requirements, and it can also form a pretty accurate judgment in regard to the first; and, in determining this much in regard to the men, the board could be of very great assistance to nontechnical mine operators in the selection of a man for this important post.

As to the other principal requirement of the mine electrician, viz, that he be sufficiently industrious to exert himself to use his abilities in the proper discharge of his duties, the board probably could not determine so definitely, but even here it could be of considerable assistance by inquiring into the previous record of service of the applicant. We have obtained expressions of opinion from a number of mine electricians in regard to this matter, and in the vast majority of cases they are unqualifiedly in favor of the proposal where the character of the proposed examination is explained to them. An examination carried out along the lines indicated in section 6 would be an eminently practical one and free from political favor or bias, and it would eliminate few, if any, men who are really competent to carry the responsibilities of a mine electrician. It would, however, eliminate from the list of possibilities not a few incompetent persons who, through some form or other of personal favoritism, might in some cases be given responsibilities that they are not properly qualified to carry. We do not see how such an examination could ever result in lowering the efficiency of mine electricians, while it appears certain that in many cases at least it would tend materially to raise the standard.

NOTE F

Rule 10.—It is a well-known fact that bituminous coal dust in considerable quantity is violently explosive in the presence of air, even though no explosive gas whatever is present. Further, a quantity of gas too small to be explosive in itself, or even to be indicated on the cap of a safety lamp, may, in the presence of a small quantity of coal dust, produce a violently explosive mixture. There are many mining engineers who believe that coal dust is more frequently the cause of explosions than gas. Inasmuch as numerous electrical phenomena, such as short circuits, blowing of fuses, arcing of air-break switches, etc., are capable of igniting any coal dust that may be present, it seems necessary that special precautions be taken to remove or keep down coal dust, or else the special rules applying to gaseous mines should be observed.

NOTE G

Rule 14.—All high-voltage wires inside of a mine should be thoroughly insulated for the reason that it is impracticable to maintain insulating supports so as not to give rise to excessive leakage over the surface when subjected to high voltage, and also to reduce the danger of electric shock.

Owing, however, to the excessively damp and acid atmosphere in most mines, all insulations at present available for commercial insulation of cables deteriorate much faster than under ordinary conditions above ground, and in time become practically worthless, and even a menace, since their presence may engender a false sense of security and actually increase the danger of electric shock. The only remedy for this is to use metal-covered cables. This would be more expensive, of course, in first cost, but the greatly increased life of the cable, together with greater freedom from trouble, would probably make it the more economical in the end, and if the lead sheath be grounded it eliminates entirely the danger of electric shock.

It seems advisable also that even with lead-covered cables the insulation should be nonhygroscopic and as nearly as possible proof against the action of mine acids, because there is always the possibility of a defect appearing in the lead sheath, either through a defective joint or through electrolytic action, or otherwise; and if paper insulation is used, even a small opening of this sort may admit enough moisture to destroy the insulation at that point and cause a breakdown. The use of nonhygroscopic insulation protected by a lead sheath seems therefore to offer the most reliable protection and should be used in all cables that are of sufficient importance to demand the use of high voltage.

NOTE H

Rule 16.—Whenever two dissimilar metals are joined together, as at the contact of a soldered joint, there exist local differences of potential which, in the presence of an excessively moist atmosphere, will give rise to more or less local electrolytic corrosion, which in time may destroy the joint. This can be largely prevented by taping or otherwise insulating the joint in such a way as to protect it from moisture. The expense of this protection is so slight as to be of no consequence, and it should therefore be applied in all cases where bare wires are used except, of course, in the case of trolley wires where it is obviously impractical.

NOTE I

Rule 22 (third paragraph).—Every overhead trolley wire is a source of danger when the pressure is on, whether the same be in use or not, but inasmuch as most branch trolley wires are actually in use only a small part of the time, it would greatly reduce the probability of electric shock if the pressure were cut off when not actually needed. If this be done, however, some sort of signal should be provided to indicate when the pressure is on, and in the dark recesses of a mine, lamps would appear to be the only suitable signal for this purpose. A number of lamps should therefore be permanently connected in series across the trolley circuit, the number depending on the voltage of the line, and the lighting up of these lamps would indicate that the trolley wire is alive. Owing to the liability of the lamps to burn out, and further since the burning out of one lamp extinguishes all those in series with it, a single circuit of this kind might sometimes, by its failure to light up, give a false signal indicating that the trolley wire is dead even when the pressure is on, which would obviously be worse than if no signal

at all were provided. To prevent this at least two such sets of lamps should be connected to the trolley circuit at every entrance to the branch roadway, so that the failure of one lamp would not cause a failure of the signal.

NOTE J

Rule 26.—Sectionalizing switches are necessary both for disconnecting certain sections of the line in cases of emergency, such as fires, short circuits, etc., and for purposes of periodic testing of the insulation.

NOTE K

Rule 35.—The question of communication between the surface and the workings of large mines is one which has not, in most cases, received as much attention as its importance deserves. Many mine managers who have expressed themselves on this subject agree that an adequate telephone system in a large mine will be worth much more than its cost merely as an aid to the regular routine operation of the mine. The delay in its general introduction may be due in part to the peculiar physical conditions which prevail in most mines, which render it difficult to maintain in proper working order, a telephone system installed on lines similar to those generally employed above ground. At the present time, however, several firms are prepared to furnish telephone systems designed especially for mining conditions, and such systems may be depended upon to give satisfactory and reliable service, provided sufficient care be taken to insure good construction of the line. Such a system would be of value not alone in facilitating the regular operation of the mine, but it might often prove to be a valuable agent in preventing mine disasters, or in reducing their severity. In order to be most effective in doing this, however, it is necessary that the construction be such as to give rise to the fewest possible interruptions. This condition is difficult to attain if the wires are placed along the side or roof of the roadways, because owing to the falls of earth, fires, explosions, and other causes, the lines might become useless when most needed. It seems probable that the most reliable working could be attained by introducing the telephone cables into the mine by way of suitably placed drill holes. In this case the main lines would be free from interruption due to falls of earth and most explosions, and fires of short duration, and might often be used to advantage in rescue work when such disasters occur.

Such a construction would generally be the most reliable one in cases of emergency, when the lives of the miners are at stake, and the great importance of this feature would seem to give ample warrant for this type of construction.

NOTE L

Rule 36.—There are some who believe that electric circuits and apparatus of all kinds should be entirely excluded from mines in which the liability of the appearance of gas is such as to render necessary or advisable the use of safety lamps. In view, however, of the great economic importance of electricity in coal mining, care should be exercised not to restrict or hamper its use more than is rendered necessary by considera-

tions of safety to life and property. There can be no question but that all types of electrical apparatus which, during normal operation give rise to sparks, arcs, or flashes, such as direct-current motors, arc lamps, trolleys, etc., are very dangerous whenever there is any great probability of the appearance of gas, and it will be generally agreed that such apparatus should be prohibited wherever conditions are such as to render necessary the use of safety lamps. With other apparatus, however, such as explosion-proof motors, polyphase motors of proper design, and well-installed circuits conveying power to such apparatus, there is comparatively little danger of igniting gas even if it should be present in explosive quantities. In fact, the ignition of gas by such apparatus is impossible except under certain comparatively rare conditions of abnormal operation—conditions which can usually be anticipated and prevented by proper periodic testing and inspection of the apparatus. It does not seem wise therefore to prohibit the use of such apparatus where gas does not exist merely because there is a possibility of its appearance. But because of the possibility of danger when gas is actually present it has been deemed wise to require the immediate shutting down of all electrical apparatus as soon as gas is found to be present in dangerous quantities. It is believed that this requirement practically eliminates the danger of an explosion arising from this source because, in view of the fact that such apparatus may often operate for days or even weeks in the actual presence of explosive gas without causing an explosion, the danger of the ignition of gas during the brief interval between its appearance and the shutting down of the apparatus seems very remote indeed.

Another rule (Rule 46) provides for cutting the pressure off from polyphase and other motors when gas actually appears.

NOTE M

Rule 45.—In many foreign laws provision is made that electric motors, switches, etc., working in gaseous mines shall be provided with flame-tight casings. Experience has shown, however, that such casings are inadequate, since it is practically impossible to maintain them in such a way as to prevent the accumulation of explosive gases within them, when such gases appear in considerable quantity in the air outside. The necessity for providing means for opening such casings for inspection, together with frequent changes in temperature caused by ordinary working, with the consequent changes in internal pressure, contribute to the difficulty of maintaining such casings free from gas. Cases have actually occurred in which explosions of gas have been caused by opening a so-called flame-tight switch. Experiments have shown that the only practicable way to operate motors, air-break switches, fuses, etc., in an explosive atmosphere is to make the casing explosion proof. In so doing it is not necessary that the case be made gas-tight, and no care need be taken to prevent gas from entering freely within the casing. The essential thing here is to make the casing of sufficient strength to resist the internal pressure developed by an explosion, and to provide an exit for the gases which will at the same time cool them to such an extent that they can not communicate the explosion to the atmosphere. This is usually accomplished by causing the gases to pass out

through a somewhat elongated passageway, across which are placed a number of fine metal gauzes, preferably of copper. In passing through these gauzes the gases are cooled successively, and by providing a sufficient number of the gauzes the temperature of the gases can be readily reduced below the flash point of the gases which are found in the mines. Other and equally effective means have been proposed, so that the requirements can be easily met by the manufacturers.

Section 6.—It is recognized that, wherever possible, the duties of the electrical inspector as set forth in the proposed code should be performed by the regular inspector of mines, and provision is made for this wherever the regular inspector is qualified to perform such duties. In many cases, however, the regular inspectors may not possess, at the outset, sufficient familiarity with electrical apparatus to inspect the electrical plant as efficiently and thoroughly as it should be done, and in most cases considerable time is necessary to acquire the requisite experience. In such cases some provision seems to be necessary for providing proper inspection of the electrical apparatus by a qualified expert until such a time as the regular inspector may acquire sufficient experience with electrical machinery and appliances to enable him to properly and safely exercise the authority of electrical inspector.

Administration of the law.—The form in which the present proposed code is drawn places the authority and responsibility for enforcing the laws in the hands of the chief of the department of mines. Such departments of mines are now in existence in most of the leading mining States, but in some States no such department exists, the supervision of mining work, where such supervision exists at all, being placed with some other branch of the state government, such as the geological survey, bureau of labor, etc. In such cases, of course, the details of that part of the law relating to its enforcement would be changed accordingly.

Liability of employers.—In inserting the clause in regard to liability of employers, it is recognized that many States now cover this point with a general liability law which includes mining within its scope, in which case this provision would not be required in the mining law. This is not always the case, however, and the importance of this provision appears to be such as to justify its inclusion here by way of suggestion.

The article in the next section on the dangers of electric wires has been prepared for the information of the mine workers, many of whom are unaware of the possibilities of accidents due to contact with wires or the short circuit of two wires. It is intended to reprint this article as a separate circular, perhaps in several languages, and to furnish copies to mine superintendents on request, to distribute among the employees of their mines. It is hoped that in justice to the mine workers an effort will be made to get this information into the hands of the men for whom it is intended.

IV. DANGERS OF ELECTRIC WIRES, AND HOW TO AVOID THEM

Electric wires used for power purposes in mines are dangerous to human life and should always be approached with caution. Deaths occur every year from electric shock, and yet in most cases these accidents could have been prevented if proper care had been exercised to prevent contact with the wires. Some men accustomed to working near electric wires grow careless, and it is largely because of this carelessness, and a lack of knowledge of the dangers involved, that so many deaths from electric shocks occur.

Special precautions are necessary in mines even where low or medium voltages are used. Everybody knows that high-voltage wires, carrying 1000 volts or more, are dangerous, and such wires are carefully avoided. But many think that circuits carrying only a few hundred volts are not dangerous. This is a serious mistake, because many deaths from electric shock occur from pressures of 300 volts or less. A considerable number of deaths have occurred from contact with circuits of less than 200 volts.

Electric circuits in mines are, as a rule, more dangerous to life than similar circuits above ground. This is sometimes due to the lack of space, which increases the liability of contact with the wires, but mainly to the damp condition of most mines. In order to receive an electric shock a man must place his body between two conductors of different electric pressures, or between one conductor and the ground. If the earth be dry, a man standing on the ground and touching the wire would receive a lighter shock than if he stood on wet ground and touched the same circuit, because dry earth is a poor electrical conductor, while wet or moist earth is a good conductor. When the skin is dry it also affords protection against low voltages, but when the skin is wet it becomes a better conductor and gives no protection. Hence, wires which might be touched with safety at one place where the ground is dry may be highly dangerous at a near-by place where the ground is moist. It is not safe, therefore, to assume that because one has touched a circuit before, or has seen some one else touch it without injury, that it is safe to touch it again. Men have frequently been killed by coming in contact with a circuit that they have often handled without harm, because, owing to different conditions of the ground, or poorer insulation of the circuit, or to a different manner of contact with the wire, the circuit is more dangerous at some times and in some places than in others. Especial care should be taken not to touch wires when standing on an iron rail or in water, as the danger is usually greatest under such conditions.

All power wires in mines of whatever voltage should be regarded as dangerous and avoided whenever possible. Insulated wires should be avoided as carefully as bare wires. Under the conditions that exist in many mines, the insulating coverings of wires become practically worthless as a protection from electric shock. Defective insulation can not always be detected by inspection, even by an expert electrician, and an insulation that appears

perfectly good to the eye may be defective, and, if touched, a severe, or perhaps a fatal, shock may result. Even lead-covered cables should be avoided, because unless the lead sheath be thoroughly grounded, which is often not the case, a shock may be received.

Special attention is called to the danger of carrying metal tools, such as drills, picks, shovels, etc., in roadways in which there are live electric wires. It is difficult to carry such tools in the limited space afforded by roadways without permitting them to come in contact with the wires. When a person holds such a tool and permits it to touch a live wire, the result is generally much more dangerous than if he had touched the wire directly with his hand, because of the fact that if he has a firm grip on the tool there is a better contact with the circuit. A large proportion of the deaths due to electric shock in mines result from carrying tools along roadways where there are exposed wires. The practice of carrying long metal tools along such roadways should therefore be avoided whenever possible, and when it becomes necessary to do so, the greatest care should be taken to keep the tools clear of the wires.

Cans of powder should never be permitted to come near to electric wires of any kind. The slightest contact of the can with the wires may often result in an explosion.

Very low voltage wires that are not likely to inflict severe shocks should, nevertheless, be regarded as dangerous. If the two wires are brought together, or if a piece of metal be connected across them, it forms what is known as a short circuit, and a blinding flash follows. This may often be so severe as to seriously injure the eyes of any person standing near, or it may inflict severe and sometimes fatal burns. Serious damage to the generating machinery may also result from such short circuits. Only experienced electricians should undertake to handle wires or operate electrical machinery.

Fires may be started as the result of a short circuit, and explosions of gas or coal dust may start in that way. It is very important, therefore, not to break an electric wire so that it may fall upon another, nor to touch the wires with any piece of metal, even when they carry the lowest voltages used in mining work.

The practice of playing with electric wires or disturbing them in any way, or of playing practical jokes, such as connecting a wire from an electric circuit to a doorknob, or to a tool for the purpose of inflicting a shock on a fellow-workman, is a dangerous practice and should never be indulged in even with very low voltage wires. Cases have been known in which the victims of such jokes have lost their lives as a result of the shock thus inflicted. Never tamper with electric circuits or apparatus in any way.

Never try to remove a wire that is found lying about or across the roadway or working places, until authorized to do so by the mine electrician or some other responsible person. It may be alive and dangerous.

Observance of the simple precautions pointed out above will serve to prevent a large proportion of accidents that would otherwise occur.

Electricity is a very useful agent in mining as in other industries. Used for haulage, coal cutting, lighting, hoists, signals, and other purposes it is of great value, and decreases the discomforts of mining. If it is properly used and the machines and wires are avoided by those not authorized to handle them, it is safe and a benefit to the miners.

V. ELECTRICAL MINING LAWS IN EFFECT IN VARIOUS STATES AND FOREIGN COUNTRIES

Up to the present time there has been very little legislation in America in regard to the use of electricity in mines. A few States have recognized the necessity of providing some sort of regulation, and have provided a few rules governing certain portions of the electrical equipment, but no law that covers the subject in anything like an adequate manner is in effect in any State. Ohio has, however, made considerable progress in its new law which has just gone into effect. Recently the department of mines in several States, notably Pennsylvania and West Virginia, have been quite active in proposing and urging legislation with a view to regulating the use of electricity in mines, but there has been a lack of concerted action between the different States, and as yet little legislation has actually been secured. In a number of foreign countries, on the other hand, a great deal has been accomplished in this direction, and comprehensive laws have been in effect for several years.

The following compilation of the electrical mining laws of the different States that have done anything in this direction, and of the principal foreign countries, has been made with a view to assisting those who are interested in the subject of regulating the use of electricity in mines, especially the departments of mines and the legislatures of the various States.

UNITED STATES

WEST VIRGINIA

There has been no law passed by the legislature of West Virginia governing the use of electricity in mines, but the department of mines has prescribed a code of rules which apply to the federal mine until such a time as the legislature may provide a general law. The department of mines has also prepared a code of rules relating to mine wiring, which it has recommended to the legislature for passage. The provisions of both of these codes are given below:

CHAPTER I.—REGULATIONS GOVERNING THE INTRODUCTION OF ELECTRICITY IN THE FEDERAL MINE PENDING A GENERAL ACT OF THE LEGISLATURE COVERING THE INTRODUCTION OF ELECTRICITY AND ITS USE IN COAL MINES IN THE STATE OF WEST VIRGINIA

1. Nothing in these regulations shall be construed as giving the sanction of the West Virginia mine inspectors to the use of any apparatus or device installed hereunder after the same has been condemned by any subsequent act of the legislature, and all rules and regulations herein mentioned and apparatus installed hereunder are to apply alone to the installation of electricity at the federal mine until such time as a general act of the West Virginia legislature shall definitely prescribe regulations covering the installation and use of electricity in coal mines and at which

time the Federal Coal & Coke Company will make its plant installed hereunder conform to the provisions of such an act.

2. The current used inside the mine will be low tension 250 volt direct current.

3. All electrical apparatus and conductors shall be sufficient in size and power for the work they may be called upon to do and so installed, worked, and maintained as to reduce the danger through accidental shock or fire to the minimum, and shall be of such construction and so worked that the rise in temperature caused by ordinary working will not be greater than demanded by fire underwriters' rules governing such installation in surface structures.

In any part of the mine where safety lamps are used the wiring shall be so hung and the insulators so constructed that there will be no danger of firing gas by short circuiting, sparking, or arcing of the current.

4. The insulation of every complete circuit other than signal or telephone wires used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit, shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current, and suitable means shall be provided for the immediate localization of leakage.

5. In every completely insulated circuit, earth or fault detectors shall be kept connected up in every generating and transforming station to show immediately any defect in the insulation of the system. The reading of these instruments shall be recorded daily in a book kept at the generating or transforming station or switch house.

6. Main and distribution switch and fuse boards must be made of incombustible insulating material, such as marble or slate, free from metallic veins, and be fixed in as dry a situation as practicable.

7. Every subcircuit must be protected by a fuse on each pole. Every circuit carrying more than 5 amperes up to 125 volts, or 3 amperes at any pressure above 125 volts, must be protected in one of the following alternative methods:

(a) By an automatic maximum cut-out on each pole.

(b) By a detachable fuse on each pole, constructed in such a manner that it can be removed from a live circuit with the minimum risk of shock.

(c) By a switch and fuse on each pole.

8. Fire buckets filled with clean, dry sand shall be kept in electrical machine rooms, ready for immediate use in extinguishing fires.

No repair or cleaning of the live parts of any electrical apparatus, except mere wiping or oiling, shall be done when the current is on.

Gloves, mats, or shoes of india rubber or other nonconducting material shall be supplied or used where the live parts of switches or machines working at a pressure exceeding the limits of the low pressure, have to be handled for the purpose of adjustment.

9. A competent person shall be on duty at the mine when the electrical apparatus or machinery is in use; and at such time as the amount of electricity delivered down the mine exceeds 200 brake horsepower, a competent person shall be on duty at the mine above ground and another below ground. Every person appointed to work any electrical apparatus shall have been instructed in his duty and be competent for the work that he is set to do.

10. No person shall wilfully damage, interfere with, or without proper authority remove or render useless any electric line or any machine, apparatus, or part thereof used in connection with the supply or use of electricity.

11. Instructions shall be posted up in every generating, transforming, and motor house containing directions as to the restoration of persons suffering from electric shock.

12. Direct telephonic or other equivalent means of communication shall be provided between the surface and the pit bottom or main distributing center in the pit.

13. Within three days after the introduction of electricity into the federal mine, notice in writing must be sent to the chief of the department of mines of the State of West Virginia that the plant is ready for inspection.

14. A plan shall be kept at the mine showing the positions of all permanent electrical machinery and cables in the mine, and shall be corrected as often as may be necessary to keep it up to a date not more than three months previously.

15. There shall be a passageway in front of the switchboard of not less than 3 feet in width, and if there are any connections at the back of the switchboard, any passageway at the back of the switchboard shall not be less than 3 feet clear. This space shall not be utilized for a storeroom or a lumber room, or obstructed in any way by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passageway must be widened accordingly.

No cable shall cross the passageway at the back of the board except below the floor, or at a height of not less than 7 feet above the floor.

The space at the back of the switchboard shall be properly floored, accessible from each end, and, except in the case of low pressure switchboards, must be locked up, but the lock must allow of the door being opened from the inside without the use of a key. The floor at the back shall be incombustible, firm, and even.

16. Every generator shall be provided with a switch on each pole between the generator and the bus bars.

Where continuous current generators are paralleled, reverse current cut-outs shall also be provided.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Every feeder circuit shall at its origin be provided with an ammeter.

17. If the transmission lines from the generating station to the pit are overhead there shall be lightning arresters in connection with the feeder circuits.

18. Automatic cut-outs must be arranged so that when the contact lever opens outward no danger exists of striking the head of the attendant. If unclosed fuses are used they must be placed within 2 feet of the floor, or be otherwise suitably protected.

19. No person other than an authorized person shall enter a machine or motor room, or interfere with the working of any machine, motor, or apparatus connected therewith.

20. All conductors (except as hereinafter provided) shall in every case be maintained completely insulated from earth, but it is permissible to use the concentric system with unearthed outer conductor, if proper arrangements are made to reduce the danger from shock or fire to the minimum, but it is not intended that any burdensome expense shall be placed upon the federal mines requiring it to exercise more than a reasonable amount of care in the present installation of cables pending the general act of the legislature heretofore mentioned.

21. The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances, must as far as is reasonably practicable be properly protected and finished off, and encased in flame proof weather proof covering.

22. All joints must be mechanically and electrically efficient, and preference given to soldered joints and in parts of the mine where safety lamps are used, flame proof joint boxes shall be installed with conductors connected by metal screw clamps. In making soldered joints in parts of the mine where safety lamps are used, the space shall first be tested for the presence of gas by the fire boss and the dust in the neighborhood dampened by water.

23. Overhead bare wires on the surface must be efficiently supported upon insulators, and clear of any traffic, and provided with efficient lightning arresters.

24. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables, not capable of sustaining their own weight, shall be properly supported

at intervals varying according to the weight of the cables. Where the cables are not completely boxed in and protected from falling material, space shall be left between them and the side of the shaft that they may yield, and so lessen a blow given by falling material.

25. When feeder cables or other cables than trolley wires are strung in haulage roads and can not be kept at least one foot from the mine cars in transit, they shall be specially protected, and where possible, carried down other parallel entries. At this mine the trolley wires will be strung upon the upcast air courses and feeder wires will be taken in the downcast. This plan, however, can be reversed at the option of the inspectors.

26. Trailing cables for portable machines shall be specially flexible, heavily insulated and protected with armoring of steel wire or extra stout braiding or other effective covering. These cables shall be examined at least once a shift by the person in charge of the machine, and defects promptly repaired.

27. Fuses and automatic cut-outs shall be so constructed as effectually to interrupt the current when a short circuit occurs, or when the current through them exceeds the working current by 200 per cent. Fuses shall be stamped or marked, or shall have a label attached, indicating the current with which they are intended to be used, or where fuse wire is used each coil in use shall be stamped or labeled. Fuses shall only be adjusted or replaced by an authorized person.

28. All live parts of switches, fuses, and cut-outs not in machine rooms, or in compartments specially arranged for the purpose must be covered. These covers must be of incombustible material, and must be either nonconducting or of rigid metal, and, as far as practicable, clear of all internal mechanism.

29. All points at which a circuit other than those for signals has to be made or broken shall be fitted with proper switches, and should this occur in parts of the mine where safety lamps are used, said switches shall be inclosed in flame-tight boxes.

30. All motors, together with their starting resistances, where used in any part of the mine in which safety lamps are used, shall be protected by switches capable of entirely cutting off the pressure and fixed in a convenient position near the motor and shall be inclosed in a flame-tight case, and where unarmored cables or wires pass through metal frames or into boxes or motor casings, the holes must be substantially bushed with insulating bushes which shall be gas-tight and can not become displaced. Terminal boxes must be securely attached to the machine and a safety lamp shall be provided for use with each such machine when working, and should any indication of fire damp appear on the flame of the safety lamp the person in charge shall immediately stop the machine, cut off the current and report the matter to an underground official of the mine.

31. The current for electric locomotives shall not exceed 250 volts and the rooms in the mine shall not be wired for the electric current and no heading shall be wired to within 25 feet of the heading brattice. The locomotives shall be in all cases gas proof as to motors, controllers, etc., and in all parts where sparking can occur except the trolley wheel and as soon as a sparkless trolley is devised or other suitable device invented that will prevent sparking at the trolley, that device shall be at once installed in this mine. The gathering locomotives shall be equipped with double cables. The bare trolley wires may be strung and insulated in the best manner practiced in other mines in the Fairmont district pending the general act of the legislature, but nothing in this clause shall permit the Federal Coal & Coke Co. to install any device in a manner not workmanlike or recognized as dangerous by the recognized standards now in force for wiring in coal mines.

32. Arc lights shall be used only at the shaft bottom if at all, and vacuum incandescent lamps at all other places in the mine. Lighting wires shall be strung as carefully in the mine as insurance rules demand for house wiring on the outside and where practicable shall be kept off the haulage entries.

33. There shall be an automatic governor switch attached to the fan shaft in such a manner that when the speed of the fan is reduced to one-half its normal number of revolutions the electric current entering the mine shall be automatically cut out at the switchboard.

34. At all times the current of air shall be made to brush each working place, and not less than two hundred (200) cubic feet of air per minute shall be furnished for each person employed in the mine.

35. No bare electric wire shall be strung or conducted through or in close proximity to any abandoned or worked out part of the mine which is not efficiently ventilated.

Approved in accordance with letter of this date.

(Signed.)

J. W. PAUL.

PITTSBURG, PA., September 9, 1908.

The following set of rules in regard to mine wiring has been recommended to the legislature for passage:

GENERAL RULES FOR MINE WIRING

1. All power circuit mine wiring must be done with approved mine type insulators and pine, 20 to 25 feet apart where the roof is low, and where the roof is sufficiently high to permit it, 30 to 35 feet apart.

2. One wire only must be placed on an insulator, securely tied with at least five turns of No. 4 copper tie wire on each side of the insulator.

3. Where conditions are such as not to permit the hanging of wire on roof, cross timbers not smaller than 3 by 4 inches must be used, placing them so as to bring all insulators as near as possible to one height.

4. The cold or negative wire must be put up and maintained with the same care as the positive, and in no instance thrown down along the entry or placed underneath road or track. All wires, when erected, must be put up with care and pulled up snug and taut, so as to remove all kinks and slack and not allowed to touch slate, coal, or timbers, but must be erected and maintained at a safe distance therefrom and not less than 10 inches apart. The practice of wedging insulators between wires or between wire and coal, etc., will not be permitted.

5. Butt entries must be wired with the same care as face and main entries and provided with two S. P. switches of approved design, of not less than 200 ampere capacity. No breakers or fuses will be permitted at these points.

6. Where face entry wires leave main line, switches must also be used.

7a. Where entries advance beyond the limit of the machine cable, No. 4 copper wire should be used for a distance of about 600 feet, or the length of a longer roll of wire. This wire is to be replaced with wire of larger size as soon as the entry has advanced sufficiently to allow the use of a complete coil without it being cut.

7b. Under no conditions are live coils to remain hanging at head of entries or at the ends of any wires and a No. 4 wire must not be employed for a greater distance than 800 feet, but must be replaced promptly with wire of larger size.

8a. No rooms or working places are to be wired.

8b. Entries must not be wired beyond the last break-through.

8c. Power circuits will not be permitted in return air-courses.

8d. The amount of wire in mines must be minimized as much as possible and where circuits are no longer necessary, the wire must be disconnected at once and removed as soon as possible.

8e. The practice of leaving wiring remain in old break-throughs, crosscuts, etc., must be discontinued and old tie wire, broken bonds, scrap wire, old cables, and coils of wire must be gathered up and kept in an orderly manner under lock and key where it may not be accessible to everyone. All scrap wire, etc., must be disposed of promptly and not allowed to accumulate in quantity.

9. The terminal ends of all large wires must be securely anchored and thoroughly insulated with a turn-buckle and strain insulator. The practice of dead ending on wood cross pieces or posts without the use of an insulator will not be permitted.

10. Whenever there is danger of the wires being touched, as, for example, where it crosses an entry, the roof should be trenched at least 10 inches deep and wire securely placed on insulators. The trench should then be covered by 1-inch boards, fastened to wooden pegs driven into the roof. The wires must not touch the board, but must be thoroughly insulated and well separated from it.

11. The practice of using jumpers will not be permitted.

12. All wire joints 2/0 or larger must be made with brass sleeves thoroughly and neatly soldered. For smaller sizes use regular Western Union joints with no less than six turns on each side, and thoroughly solder.

13a. Where wires go through wooden or brick brattice work or other partitions, they must be thoroughly protected with porcelain tubes. The tubes, if in wood partitions, must be held in place with tape; if in brickwork, they must be cemented so that they can not be moved.

13b. Where partitions, brattices, etc., are built after wires have been erected, split tubes must be used to avoid the cutting of wires.

14. In wiring entries where grounded circuit is used, care must be taken that the positive or hot wire is always placed next to the rib, the negative or cold wire being placed 10 inches on the outside of the hot wire.

15. The practice of hanging wires on nails, whether wire is insulated or not, will not be permitted and wood cap pieces, etc., must not be used to keep wire away from the ribs under any circumstances.

TROLLEY WIRE AND BONDING

1. Trolley wire may be suspended inside the mine on hangers, lag screwed to cross timbers, or, where roof will permit, on wooden blocks 3 by 4 by 18 inches, bolted to roof.

2. All new trolley will be of the standard grooved pattern; care must be taken that no kinks, sharp turns or dents from come-alongs are made in it.

3a. The center of each hanger should be plumbed 7 inches outside the outer edge of rail. Hangers should be placed about 20 feet apart on straight entries in low coal and 35 feet apart in high coal. Considerable latitude will have to be allowed, as no specific rule can be made for distance apart of hangers, but the above is a fair average when wire is erected and maintained properly. On curves, the distance should be 8 feet to 10 feet apart and strain of wire from pulling the hanger sidewise. Use No. 6 steel wire to guy the strain ear and spherical strain insulator. On sharp curves, curve ears can be of great assistance in holding wire.

3b. Barn hangers are provided with four holes, while two holes diametrically opposite are sufficient. Use a 1/2 by 2 1/4 inch gimlet point lag screw, drilling holes for same with three-eighths twist bit. Do not use track spikes or nails for fastening hanger bodies to timbers.

4. Frogs should be placed 10 feet to 12 feet back from point of latch and held in horizontal position by properly placing hangers on line near frogs. Guys of No. 6 galvanized steel wire will assist materially in relieving the strain on frog and holding it in proper position. Insulate guy at frog by use of spherical strain insulator.

4b. Frogs must be placed at each point where branches leave main trolley and when properly placed will not necessitate the holding of pole when passing over frog at ordinary speeds.

5. Automatic trolley switch and signal lights must be placed at all partings where mules will pass under the trolley. Automatic switches are not expected to sustain severe strains and should be relieved of such by proper disposition of strain ears and hangers.

6. The ends of trolley wire must be securely anchored and thoroughly insulated with turn-buckle and strain insulator. A three-bolt galvanized clamp should be used for fastening end of wire when wire is bent back on itself through strain insulator.

7. Care must be taken that the trolley wire clears the roof, so that wheel will not touch roof at any time.

8. Where feeders are necessary they must be erected the same as main lines and tapped in at proper intervals by means of feeder cars. The practice of hooking a jumper around an ordinary hanger must not be allowed.

9. At end of motor road where machine lines ground to rail or at points where rail circuit returns to plant, it is well to use several bonded wires leading to return and to bond each individual wire into rail in more than one hold; also provide cross bond at this point.

10a. Bond both sides of track, using nine-sixteenths inch channel pins and No. 0 soft copper wire only.

10b. Be careful to drill holes to exact size, using nothing other than nine-sixteenths inch twist drills.

10c. Bonds must be placed on outside of rails and extended at least 3 inches beyond fish plates and cut to such lengths as will allow removal of fish plates without disturbing bond.

10d. Cross bonds every fifth rail, making bond of sufficient length that it may be bent down below top of ties so as not to be interfered with.

MINE LIGHTING

1a. Where it is necessary to wire partings, slopes, curves, pump houses, etc., use receptacle and No. 12 triple braid, weatherproof wire and No. 4 porcelain knobs.

1b. No rosettes, snap switches, or ordinary sockets can be used in interior of mine.

2. No switches or fuses will be required. Where a large number of lights are used fuses and switches can be used to advantage.

3a. The practice of hooking ends of light wires over power circuits must be discontinued and connections made in such a manner that vibration of line will not form arcs, burning large wire.

3b. Where it is necessary to turn lights on and off frequently in interior of mine, knife switches should be used.

OHIO

The following law was in effect in Ohio until June 10, 1910:

An Act to protect the lives of persons employed in the mines of Ohio against the dangers of electricity and machinery and providing penalties for violation.

Be it enacted by the General Assembly of the State of Ohio:

Section 1. That after three months from the passage of this act, in all mines in this State where electricity is or hereafter shall be used as a part of the system, power, or means of mining and producing the coal from any of said mines, that the owner or operator of every such mine shall cause all wires conducting electricity in and about said mines to be carefully and thoroughly insulated or protected in a safe manner as may be authorized by the state mine inspector or his deputy, so that persons or animals coming in contact therewith will not be injured thereby. Provided, however, that trolley wires or other wires not capable of insulation shall be guarded by being placed at least three (3) inches deep within a groove or in such other manner as may be authorized by the state mine inspector or his deputy, whose duty it shall be, upon the written request of any mine owner, operator, or person employed in such mine, to investigate all such wires that may be incapable of insulation and determine upon any proper method of guarding said wires other than by means of the aforesaid groove.

Insulating electric wires; guarding wires not insulated; certificate of inspector

And said inspector shall thereupon issue a certificate to the owner or owners of said mine setting forth the method to be employed in the guarding of said wires, and keep a record of the same; thereupon, within thirty (30) days from date of the certificate, it shall be the duty of the mine owner or operator to guard such noninsulated wires in the manner required in said certificate.

**Shield for min-
ing machines**

Sec. 2. In all mines where mining machines are used, each of said machines shall be equipped and provided with a sufficient shield as may be authorized by the state mine inspector or his deputy, for the protection of those employed in or about the use and operation thereof; and said shield shall be kept in use constantly while said machine is under operation.

Penalty

Sec. 3. Any corporation or person violating the provisions of section one of this act shall be fined not more than five hundred dollars nor less than one hundred dollars; and for the violation of section two of this act not more than one hundred dollars.

FREEMAN T. EAGLESON,

Speaker of the House of Representatives.

JAMES M. WILLIAMS,

President of the Senate.

Passed May 9, 1908.

Approved May 9, 1908.

ANDREW L. HARRIS, *Governor.*

A new general mining law recently passed by the Ohio legislature, and which went into effect June 10, 1910, contains the following provisions in regard to the use of electricity:

Sec. 947. The owner, lessee, or agent of a mine in which electricity is used as a means of power, shall observe the following in the application thereof:

All trolley wires shall be carried at least 6 inches outside of and parallel with the track rail on the side the trolley wire is located. When regular height is less than 6 feet 6 inches from top of rail, the lower side of trolley wire must not exceed 6 inches from the roof or cross timber with hangers now in use, with hangers not to exceed 25 feet between centers, and the tension sufficient to keep all wires from sagging and to prevent trolley wheel from coming in contact with roof or cross timbers. All new hangers hereafter installed shall not exceed 5 inches in depth from lower side of the trolley wire to the roof or cross timbers.

All trolley and positive feed wires crossing places where persons or animals are required to travel, shall be safely guarded or protected from such persons or animals coming in contact therewith.

All trolley and positive feed wires shall be placed on opposite side of track from refuge holes or necks of rooms.

No trolley wire shall be extended into or maintained in any room while being used as a working place; no trolley or feed wire shall be extended into any entry beyond the outside corner of the last break-through.

Switches or circuit breakers shall be provided to control the current at the mine, and at all important points in the mine.

All machine feed wires shall be placed as near the rib and roof or cross timbers as practicable; the positive wire to be carried not to exceed 3 inches from the rib and roof or cross timbers, measured at the insulators, which shall be so placed as to keep the wire at least 6 inches outside of the track rail on the side the wire is located. Insulators shall be placed not exceeding 50 feet apart, and all wires shall be carried so that same will be not less than 6 inches outside of the track rail at any point on the side the wire is located. All positive wires shall be carried on glass or porcelain insulators, or insulators equally efficient. All negative wires shall be carried on suitable fixtures, and when carried in same entry as the positive wire, shall be carried

on the same side of the entry as the positive wire, and as close to it as practicable. When machine or feed wires are carried in same entry as trolley wire, they shall be placed on the same side as the trolley wire, between trolley wire and rib. Nothing in the foregoing shall require negative wires being carried in same entry with positive wire.

When necessary to carry wires down shafts or slopes used as traveling ways, the wires must be thoroughly cased or protected, so that persons can not be shocked therefrom.

Positive machine feed wires, when extended into rooms, shall be placed not nearer than 4 feet of the track, where the room is of sufficient width, and the same shall only be connected to the positive wire or wires on the entry while in actual use. The material used for making such connection shall be of sufficient length to reach across the entry, and when same is disconnected, it shall be kept with the machine operating at such point or working place. No electric wires shall be extended into any room unless a 150-foot cable will not reach the face of the room, and then not beyond the outside corner of the last break-through.

All terminal ends of positive wires shall be guarded so as to prevent persons inadvertently coming in contact therewith.

The bonded track, the negative wires and metallic pipe lines, when coming near each other, may be connected together at intervals not exceeding 500 feet, and any track used as the return or earth system shall be properly bonded. In no case shall a pipe line, or any part thereof, be used exclusively as the return, and when connected to the earth system, the negative wire or bonded track shall be of ample capacity, exclusive of the pipe line, to carry the current.

The trolley wire shall be carried upon hangers or other fixtures which will properly insulate it from contact with the roof or other substances, and so the trolley wheel can trail without the necessity of being constantly attended for that purpose, and no trolley shall be run on any wire not so carried. No locomotive shall be operated by means of a person holding and sliding upon or frequently making contact with the positive wire with any device attached to the cable as a substitute for a trolley, but these provisions shall not prohibit the operation of a locomotive by means of a cable without the use of the trolley, provided the cable be connected to and disconnected from the positive wire when the locomotive is not in motion. Means shall be provided by which machine runners may readily carry the machine cable from the machine to the feed wires on one side of the entry, either under or over the track rails, in the entry where such wires are located, and so the cable will not come in contact with such track rails, thereby reducing the danger of shock to persons or animals required to travel such entry to the minimum.

SEC. 948. The owner, lessee, or agent of a mine at which electricity with a pressure or potential of more than 325 volts, or alternating current, is used shall, in addition to the provisions of the preceding section, observe the following:

At each mine equipped with electric power after the passage and approval of this act, the current used to operate gathering locomotives, mining machines, shearing machines, drills, and other machinery used in or about the working places of the mine, shall not exceed in pressure or potential 325 volts, direct current, as shown at the nearest switchboard, and the wires conducting the power from the nearest switchboard shall not carry a higher pressure or potential.

At each mine equipped with electric power after the passage and approval of this act no alternating current shall be used under ground to operate any machinery other than that necessary to convert the alternating current to direct current, and no wires carrying alternating current shall be used under ground except same be carried in an entry or passageway where persons and animals are not permitted to travel.

At each mine equipped with electric power after the passage and approval of this act, when the current used to operate haulage locomotives, pumps, and other machinery not located in or about the working places of the mine is of a pressure or potential in excess of 325 volts, direct current, the entry or passageway where such wires are carried shall not be designated or permitted to be used as the principal traveling way, and when designated or used as the escapement way, the wires shall be protected so that persons required to travel near same in emergencies will not inadvertently come in contact therewith. No pressure in excess of 650 volts at the switchboard shall be used under ground.

At each mine equipped with electric power prior to the passage and approval of this act, where the pressure or potential is in excess of 325 volts, direct current, or where alternating current is used, and the conditions surrounding the use of same are such, in the opinion of the chief inspector of mines, that the provisions of the preceding section do not provide the required protection from shock to persons employed therein, such additional safeguards shall be employed as may be required by the chief inspector of mines and the district inspector of mines, jointly.

IDAHO

The mining laws of Idaho make but brief reference to electricity. The two following clauses are the only ones that have any bearing on this subject:

Every working adit or cross-cut tunnel entrance, where wooden buildings exist at or near the portal of same, shall be provided with a fire door not less than 50 feet in from the earth portal of the tunnel. This door shall be hung and so adjusted that upon being released it will close of its own accord, either by its own weight when hung from the top of the tunnel or by means of suspended weights when hung from the side. The door shall be held open by a rope passing over a pulley, terminating outside of any of the buildings at the mouth of the tunnel, and shall be so fitted that when closed it will cut off the circulation of air as completely as possible. Where electric haulage is used in said adit or cross-cut tunnel, a door consisting of two doors hung from the sides and closing tightly can be used.

Electric power cables, where used under ground, shall be thoroughly insulated; and where electric haulage is used underground, the trolley wires must be protected by inverted U-shaped guards, placed along the trolley wires, opposite any hand-loading chutes.

MONTANA

In the Montana laws it is provided that if electricity is used for shot firing the voltage must not exceed 250 volts. It is also required that if telephone systems are used they must be inspected daily; and where electric bells are used a simple code of signals is prescribed.

MISSOURI

The Missouri mining laws contain the following provision:

Electric blasting in shafts.—At all mines where 10 or more men are employed on any shift, all holes in the shaft must be fired by an electric battery placed above ground, and in no case shall caps and fuse, or any other method than electric blasting, be employed for exploding holes in shaft.

KANSAS

The only law relating to electricity in mines in Kansas is the following:

No powder shall be delivered by hauling the same in any car hauled by an electric motor unless the car in which the powder is hauled for delivery is thoroughly insulated.

PENNSYLVANIA

The following code of rules has been prepared by the state department of mines of Pennsylvania. It was presented to the state legislature in 1909 for passage, but failed of enactment.

ARTICLE IX.—SPECIAL RULES FOR THE INSTALLATION AND USE OF ELECTRICITY

The following rules shall be observed, as far as is reasonably practicable, in the mines:

DEFINITIONS

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth, as read by a volt-meter, and,

(a) Where the conditions of the system are such that the pressure at the terminals where the electricity is used can not exceed two hundred and fifty volts, this shall be deemed a low-pressure system.

(b) Where the conditions of the system are such that the pressure at the terminals where the electricity is used between any two conductors, or between one conductor and earth, may at any time exceed two hundred and fifty volts, but can not exceed five hundred and fifty volts, this shall be deemed a medium pressure system.

(c) Where the conditions of the system are such that the pressure at the terminals where the electricity is used between any two conductors, or between one conductor and earth, may at any time exceed five hundred and fifty volts, this shall be deemed a high-pressure system.

The expression "the minimum" signifies the least reasonably possible to be attained by the proper use of the means from time to time known and available, so as to secure safety with efficiency.

SECTION I

Rule 1.—All electrical apparatus and conductors shall be sufficient in size and capacity for the work they may be called upon to do, and so installed, worked, maintained, and safeguarded, as to reduce the danger from accidental shock or fire or over heating to the minimum, and shall be of such construction, and so worked, that the rise in temperature caused by ordinary working will not injure the insulating materials.

In any mine, or any part of a mine where safety lamps are used, the covering of motors or cables shall be so constructed that there is no danger of firing gas by sparking or flashing which may occur during the normal or abnormal working of the apparatus.

All metallic coverings or armoring of cables, and the frames and bedplates of generators, transformers, and motors, other than portable motors, shall be efficiently grounded if the pressure at the terminals where the electricity is used exceeds the limits of low pressure.

Rule 2.—Where a medium pressure system is used for power purposes, or for arc or incandescent lamps, the conductors which form the connection to the motors, transformers, or lamps, or are otherwise used in connection with the system, shall be completely inclosed in strong armoring or metal casing, or they shall be fixed at such a distance apart, or in such a manner, that danger from fire or shock shall be reduced to the minimum. This rule shall not apply to trailing cables, which are dealt with under rules 27 to 32.

Rule 3.—Motors of coal-cutting and other portable machines, shall not be used at a pressure higher than a medium pressure.

Rule 4.—A higher pressure than a medium pressure shall not be used under ground, except for transmission or for application to transformers or other apparatus in which the whole of the high pressure circuit is stationary.

All high pressure machines, apparatus, and lines, shall be so marked by the use of the word "Danger" at frequent intervals, or by red paint properly renewed when necessary, or in some other conspicuous manner, as to indicate clearly that they are high pressure and dangerous.

For work under ground, when furnished with current at a pressure higher than medium pressure, a transformer shall not be of less normal rating than 5 kilowatts, nor shall a motor be of less normal rating than 20 brake horsepower.

Rule 5.—In any mine, or any part of a mine, where safety lamps are used, a higher pressure than a medium pressure shall not be transmitted beyond the last cut-through of the intake entries, and all motors, transformers, and other apparatus connected with such high pressure system, must be placed in suitable chambers ventilated by intake air.

Rule 6.—In every completely insulated circuit ground detectors shall be kept connected in every generating station to show immediately any defect in the insulation of the system. These instruments shall be inspected daily by a competent person or an automatic recording instrument shall be used.

Rule 7.—Main and distribution switch and fuse board in the mines shall be made of incombustible, insulating material, such as marble, or slate free from metallic veins, and be fixed in as dry a situation as practicable.

Rule 8.—No repairing of the live parts of any electrical apparatus, except cleaning or oiling, shall be done when the current is on.

Where the live parts of switches, or machines working at a pressure exceeding the limits of low pressure, may have to be handled for the purpose of adjustment, or for such wiping or oiling, insulating gloves, or mats of india rubber or other suitable material, shall be supplied by the operator and shall be used by the attendants.

Rule 9.—At every gaseous mine where electricity is used below ground for power, there shall be employed a competent mine electrician who shall be subject to the authority of the mine foreman and superintendent, and shall have full charge of all electrical machinery and apparatus in the mine. The mine electrician, or an assistant mine electrician, shall be on duty at the mine when the electrical apparatus or machinery in use for the production of coal requires more than 25 horsepower.

After the expiration of twelve months from the passage of this act no person shall be allowed to act as a mine electrician, or as an assistant mine electrician, in a gaseous mine unless he shall be the holder of a certificate of competency issued by the department of mines.

Every person appointed to operate any electrical apparatus in a mine shall have been instructed in his duty by the electrician or mine foreman.

Rule 10.—Fire buckets filled with clean dry sand shall be kept in the mines where stationary electrical apparatus is located ready for immediate use.

Rule 11.—Instructions shall be posted at the mine entrance and in every generating, transforming, and motor house for the resuscitation of persons suffering from electric shock. All employees working in connection with the electrical apparatus shall be required to acquaint themselves with these instructions.

Rule 12.—A plan on a scale not smaller than 200 feet to the inch shall be kept at the mine showing the position of all permanent electrical machinery and fixed cables or conductors in the mine, and shall be corrected as often as may be necessary to keep it as nearly as practicable up to date, and never more than three months in arrears. Such plan shall, so far as is consistent with this rule, be subject to the same conditions as are provided by article one of this act in relation to the plan therein mentioned.

Rule 13.—Every personal accident occurring in connection with the operation of electrical equipment shall be promptly reported by the person injured, or by some other person on his behalf, to the mine foreman, and shall be recorded by him at the office of the mine.

Rule 14.—In the event of a breakdown of, or damage or injury to, any portion of the electrical equipment in a gaseous mine, or of overheating, or of the appearance of sparks or arcs outside of inclosing casings, or in the event of any portion of the equipment (not being a proper part of the electrical circuit) becoming alive, every such occurrence shall be promptly reported to the mine foreman.

SECTION II.—*Generating stations and machine rooms*

Rule 15.—Where the generating station under the control of the owner or superintendent of the mine is not within 500 feet of the mine entrance, a switch box or boxes, efficiently inclosed and locked, or a locked switch house, shall be provided near the mine entrance for cutting off the supply of electricity to the mine.

Rule 16.—All terminals and live metal on machines over medium pressure above the ground, and over low pressure under ground, shall, where practicable, be protected with insulating covers, or with metal covers connected to earth.

Rule 17.—If the transmission lines from the generating station to the mine are overhead, and exceed 500 feet in length, there shall be lightning arresters in connection therewith at the mine entrance.

SECTION III.—*Cables*

Rule 18.—All high pressure wires used inside of the mines shall be in the form of insulated, lead-covered or armored conductors, subject to insulation tests, and with carrying capacity according to the rules of the American Institute of Electrical Engineers.

Except in gaseous mines, all medium or low pressure conductors may be bare or with high class insulation. If bare wire is used all feed wires must be shielded and properly protected at all points where there is danger of men or animals coming into contact with them. In gaseous mines no bare conductors shall be used in rooms, or in room entries, or beyond the last cut-through in other intake entries.

Rule 19.—The size of the conductor (except in the case of overhead wires upon the surface) shall be determined in accordance with the table showing maximum current for copper conductors as designated by table prepared by the American Institute of Electrical Engineers.

Rule 20.—One side of all grounded circuits must be efficiently insulated from earth.

Where lead-covered or armored cable is used the lead or armor shall be earthed and shall be electrically continuous throughout.

Rule 21.—The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances, shall be properly protected and finished off so that moisture can not creep along the insulating material within the waterproof sheath, or insulating material, if of an oily nature, leak out of the cable.

Rule 22.—All joints must be mechanically and electrically efficient and, where practicable, must be suitably soldered.

Rule 23.—Overhead bare wires on the surface shall be properly secured to insulators, and clear of any traffic, and provided with lightning arresters.

Rule 24.—In any mine, or any part of a mine, where safety lamps are used, the main cables shall be taken into the mine by way only of an intake airway.

Rule 25.—All cables used in shafts must be highly insulated and substantially fixed. Shaft cables not capable of sustaining their own weight shall be properly supported at intervals varying according to the weight of the cable. Where the

cables are not completely boxed in and protected from falling material space shall be left between them and the side of the shaft that they may yield and thus lessen a blow given by falling material.

Rule 26.—Where the cables in main haulage roads where persons are hauled into or out of the mines can not be kept at least one foot from any part of the car they shall be specially protected.

Cables and wires, unless provided with metallic coverings, shall not be fixed to walls or timbers by means of uninsulated fastenings.

Cables under ground, when suspended, shall be supported flexibly in such a manner as to allow of their readily breaking away when struck before the cables themselves can be seriously damaged.

Where main or other roads are being repaired or blasting is being done temporary protection must be used so that the cables are protected from damage.

Rule 27.—Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with extra stout braiding, hose pipes, or other equally effective covering.

Rule 28.—The joints, if any, made in trailing cables, shall be soldered. Clamps of any kind must not be used for this purpose.

Rule 29.—The two cables of the twin trailing cable shall be divided at the motor, and only for such a length as is necessary for the making of connection to the motor, and the twin cable, with its outer covering complete, shall be securely held by a suitable clamp on the motor frame in such a manner as to protect the trailing cable from injury, and to prevent any mechanical strain being borne by the single ends making electrical connection with the motor.

Rule 30.—In the event of the trailing cable in service breaking down or being damaged in any way, or of its inflicting a shock upon any person, it shall be at once put out of service and another cable shall be substituted therefor. The faulty cable shall not be used again until it has been repaired and tested by the mine electrician.

Rule 31.—In gaseous mines each trailing cable in use shall be examined daily by the machine boss for abrasions and other defects.

The machine man shall also be required to observe carefully the trailing cable while in use in order to detect defects, and in the event of any defect becoming apparent notice of the same shall at once be sent to the mine electrician or the assistant mine electrician.

Rule 32.—The trailing cable shall be kept disconnected from the machine while it is being loaded on to, or unloaded from, the truck, unless the construction of the machine is such that the electric power is necessary for its unloading or reloading. Sections twenty-seven, twenty-eight, twenty-nine, thirty, thirty-one, and thirty-two do not apply to electric gathering locomotives.

SECTION IV.—*Fuses, circuit breakers, and switches*

Rule 33.—Fuses and automatic circuit breakers shall be so constructed as to open the circuit when the current through them exceeds by 100 per cent the working current in the case of motors, or the permissible current of the cables which these devices protect. Fuses shall be stamped or marked, or shall have a label attached, indicating the current at which they are intended to fuse, or where fuse wire is used each coil in use shall be so stamped and labeled. Fuses shall only be adjusted or replaced by a competent person authorized by the mine foreman, except in case of coal-cutting machines and electric locomotives, when the machine runners and motormen shall be permitted to adjust or replace them.

Rule 34.—All switches, circuit breakers, and fuses must have incombustible bases of marble, slate, or porcelain, or other suitable incombustible insulating material.

Rule 35.—All points at which a circuit (other than those for signals or portable motors) has to be made or broken shall be fitted with proper switches. In any mine, or any part of a mine, where safety lamps are used the use of hooks or other makeshifts is prohibited, and switches, circuit breakers, and fuses (except as provided for in rule 41 hereafter) shall not be of the open type, but must either be inclosed in gas-tight boxes or break under oil.

SECTION V.—*Motors*

Rule 36.—Every stationary underground motor, together with its starting resistance, shall be protected by a fuse or circuit-breaking device in accordance with rule 34, and by switches capable of entirely cutting off the pressure. The switches shall be fixed in a convenient position near the motor and every stationary motor of 100 brake horsepower or over underground shall be provided with a suitable ammeter to indicate the load on the machine.

In any mine, or any part of a mine, where safety lamps are used all mining machines, with their cables, shall be protected against overloads or excessive currents by a completely inclosed and flame-proof fuse.

Rule 37.—Where unarmored cables or wires pass through metal frames, or into boxes or motor casings, the holes shall be substantially bushed with insulating collars and, where necessary, with gas-tight bushings which can not readily become displaced.

Rule 38.—The terminal of connections, or cables for portable motors, shall be securely attached to the machine.

Rule 39.—Where the insulation of a motor is found to become damp during a stoppage, suitable steps shall be taken to insure that the insulation shall be dry before the working of the motor is resumed.

Rule 40.—In any mine, or any part of a mine, where safety lamps are used, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current-carrying parts, also their switches, starters, terminals, and connections completely inclosed in such a manner as to prevent the escape of sparks or flame into the gaseous atmosphere, the inclosures to be made of incombustible material and of sufficient strength to escape damage in the event of an explosion of fire damp occurring in the motor, and such inclosures shall not be opened except by an authorized person, and then only when the current is switched off. The pressure shall not be switched off while the inclosures are open.

Rule 41.—In any mine, or any part of a mine, where safety lamps are used, a safety lamp or other suitable apparatus for the detection of explosive gas shall be provided for the use of the attendant of stationary electrical apparatus, and should any indication of explosive gas appear on the flame of the safety lamp or other apparatus used the person in charge shall immediately stop the machine, cut off the current at the nearest switch and report the matter to the mine foreman.

Rule 42.—The mine foreman shall not place a man in charge of a coal-cutting machine in a gaseous mine who is not a competent person capable of determining the safety of the roof and sides and detecting the presence of explosive gas.

Rule 43.—In any mine, or any part of a mine, where safety lamps are used, before a coal-cutting machine is brought within 20 yards of the working face, the machine man shall make an inspection for gas in the place where the machine is to work unless such an examination is then made by some other competent person authorized or appointed for that purpose by the mine foreman. If any explosive gas is found in the place, the machine shall not enter therein.

No coal-cutting machine shall be continued in operation for a longer period than half an hour without an examination as above described being made for gas, and if gas is found the current shall at once be switched off the machine and the trailing cable shall forthwith be disconnected from the feed wire.

The person finding the gas shall at once erect a danger signal to warn persons against entering the place. The trailing cable shall be removed from such place.

This cable shall not be brought back nor shall the machine be again started in such place until the fire boss, or a person duly authorized by the mine foreman, has examined it and has pronounced it free from gas and has removed the danger board.

The person finding gas shall forthwith report the same to the mine foreman, and at the end of the shift he shall make and sign a written report in a book kept at the mine for the purpose.

Rule 44.—In order that the roof may be carefully examined, a coal-cutter motor shall not be kept continuously at work for a length of time exceeding half an hour.

Rule 45.—The person in charge of a coal cutting or drilling machine shall not leave the machine while it is working, and shall, before leaving the working place, see that the pressure is off from the trailing cables. No repairs shall be made to any portable machine until the pressure has been cut off.

Rule 46.—In gaseous mines, if any sparks or arcs appear outside the casing of a coal-cutting or other portable motor, or about the cables or rails, the machine shall be stopped and shall not be worked again until the defect has been repaired, and the occurrence shall be reported to the mine foreman or to the assistant mine foreman.

Rule 47.—All inclosed motors used underground shall be opened and inspected by the mine electrician or his assistant at least once a week and, where necessary, shall then be cleaned and repaired. Inclosed switches shall be opened and inspected at least once every month.

SECTION VI.—*Electric locomotives*

Rule 48.—Electrical haulage by locomotives on the trolley wire system shall not be allowed in that part of a mine where locked safety lamps are used.

Rule 49.—In underground roads the trolley wire shall be sufficiently guarded, or the pressure must be cut off from the wires at all times when such roads are used for traveling on foot. The hours during which traveling on foot therein is permitted shall be clearly indicated by notices and signals placed in conspicuous positions at the ends of, and at all entrances into, the roads. At other times no one except a duly authorized person shall be permitted to travel on foot along such roads.

Rule 50.—On underground roads the trolley wires shall be placed as close to the side, and as near in a straight line, as practicable, and securely supported at frequent intervals. On any part of the trolley system where it is necessary for men to cross under the trolley it shall be so guarded that the possibility of contact will be reduced to a minimum, and lights shall be placed at all such crossings.

At all landings, turn-outs, or partings, and such other places as men are required to work near or pass under the wire, a suitable protection shall be placed. This protection may consist of channeling the roof, placing boards along the wire which shall extend 3 inches below, or the use of other approved devices that afford protection, or the wire may be placed 6 feet above the top of the rail. All branch trolley lines shall be fitted with an automatic trolley switch, or section insulator and line switch, or some other device that will allow the current to be shut off from such branch headings. Lights shall be placed along the branch headings to indicate when the power is on.

Rule 51.—It is recommended that where air or water pipes parallel the grounded return of power circuits, the return be securely bonded at frequent intervals to such pipes to eliminate the possibility of a difference of potential between rails and pipes, and to prevent electrolysis of the pipes. The rail return shall be of sufficient capacity for the current used independent of the capacity of the pipes.

Rule 52.—If storage battery locomotives are employed in any mine or part of a mine where safety lamps are used, the rule applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

SECTION VII.—*Electric lighting*

Rule 53.—Arc lamps used underground shall be so guarded as to prevent pieces of heated carbon falling from them, and they shall not be used in situations where there is likely to be danger from the presence of coal dust. They shall be so screened as to prevent risk of contact with persons.

Rule 54.—Small wires for lighting circuits shall either be conveyed in pipes or casings, or they may be suspended from porcelain insulators, or securely tied to them so that they do not touch any timbering, coal, or metal. On no account shall staples be used. If metallic pipes are used, they must be electrically continuous and grounded. If separate uncased wires are used, they shall be kept at least 3 inches apart and not brought together except at lamps, or switches, or fittings.

Rule 55.—In any mine or any part of a mine where safety lamps are used, electric lamps, if installed, must be of the vacuum, or inclosed type, and they shall be protected by gas-tight fittings of strong glass, and shall have no flexible cord connections. Electric lamps shall be replaced by a competent person only.

Rule 56.—In gaseous mines, in all machine rooms, and other places underground where a failure of electric light is likely to cause danger, some safety lamps, or other proper lights, not fewer than a number to be prescribed for such place by the inspector, shall be kept for use in the event of such failure.

SECTION VIII.—*Shot firing*

Rule 57.—Electricity from lighting or power cables shall not be used for firing shots.

Rule 58.—When shot-firing cables or wires are used in the vicinity of power or lighting cables sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming into contact with the lighting or power cables.

Rule 59.—In gaseous mines only competent persons who have been properly instructed in the work, and duly authorized in writing, shall be allowed to fire shots electrically in any part of a mine.

Rule 60.—The exploder fuses and wires shall be suitable for the conditions under which the blasting is carried out and shall be of an approved type.

Rule 61.—High tension magneto-generators shall be inclosed in flame-tight cases when employed in any mine or any part of a mine where safety lamps are used.

Rule 62.—A primary or secondary battery, when used for shot firing, shall be inclosed in a suitably constructed box fitted with a removable connecting plug or key without which the circuit can not be closed. This plug or key shall be detached when not required for firing, and shall not under any conditions pass from the personal custody of the shot firer while on duty. Such batteries shall be frequently tested by the shot firer to insure that they give the necessary pressure and current.

Rule 63.—The exploder shall be in the charge of the shot firer and shall be fitted with a handle or key which shall be detached when not required for firing, and shall not under any conditions pass from the personal custody of the shot firer while on duty.

Rule 64.—The exploder shall not be connected to the shot-firing cable until all other steps preparatory to the firing of the shot have been completed and all persons have removed to a position of safety.

Immediately after the firing of the shot the firing cable shall be disconnected from the exploder, and no person shall approach a shot that has been attempted to be fired by electricity and has failed to explode until the firing cable has been so disconnected, and an interval of five minutes has elapsed since the last attempt to fire the shot.

The foregoing rules shall not apply to apparatus used for telephone, telegraph, and signal purposes, which are provided for by the three following rules.

SECTION IX.—*Signaling*

Rule 65.—All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not.

Rule 66.—Bells, wires, insulators, contact-makers, and other apparatus used in connection with electric signals underground shall be of substantial and reliable description and shall be erected in such a manner as to reduce the liability to failures or false signals to the minimum.

Rule 67.—In any mine, or any part of a mine, where safety lamps are used, the pressure employed for signaling purposes shall not in any one circuit exceed 50 volts in an intake air way, or 50 volts elsewhere, and bare wires shall not be used for such purposes except in haulage roads.

SECTION X.—*Electric relighting of safety lamps*

Rule 68.—If in any mine, or part of a mine, in which safety lamps are used, they are relighted underground by electricity, the mine foreman shall select a suitable station or stations not being in the return airway and where there is not likely to be any accumulation of inflammable gas, and no electric relighting apparatus shall be used in any other place. All electric relighting apparatus shall be securely locked and shall not be available for use except by persons authorized by the mine foreman to relight safety lamps, and such persons shall examine all safety lamps brought for relighting before they are reissued.

No other States have any laws relating to the use of electricity in mines.

FOREIGN COUNTRIES

GREAT BRITAIN

In 1902 a committee was appointed by the British Home Office to investigate the use of electricity in mines, and this committee made its report in 1904, in which the following set of rules was recommended.

RULES FOR THE INSTALLATION AND USE OF ELECTRICITY IN MINES

DEFINITIONS.

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth as read by a hot-wire or electrostatic voltmeter, and

- | | |
|----------------------------|--|
| Low pressure | (a) Where the conditions of the supply are such that the pressure at the terminals where the electricity is used can not exceed 250 volts, the supply shall be deemed a low pressure supply. |
| Medium pressure | (b) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250 volts, but can not exceed 650 volts, the supply shall be deemed a medium pressure supply. |
| High pressure | (c) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 650 volts, but can not exceed 3,000 volts, the supply shall be deemed a high pressure supply. |
| Extra high pressure | (d) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts, the supply shall be deemed an extra high pressure supply. |

SECTION I.—General

1. The whole of the machinery, material, and workmanship in connection with the supply and use of electricity shall be the best of its respective class, and sufficient in size and power for the work it may be called upon to do. Quality of installation

2. All electric machinery shall be installed as far as is practicable in dry, well-lighted, and well-ventilated places. Installation of machinery

3. All electrical apparatus shall be so worked that the rise in temperature will not injure its insulating materials. Apparatus to work without undue heating

4. All live metal work, such as commutators, slip rings, resistances, switches, starters, cut-outs, shall be substantially made and effectively covered or guarded so as to avoid danger through accidental shock or risk of fire. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, the covering shall be constructed so that there is no danger of firing gas by any sparking or flashing which may occur during the normal or abnormal working of the apparatus. All metallic coverings shall as far as practicable be effectively earthed where the pressure exceeds the limits of low pressure. Protection of live metal work; complete inclosure of same where gas is liable to be present; earthing of metallic coverings

5. The pressure of a supply delivered to the motor or other terminals shall not exceed the limits of a low pressure supply, unless the following conditions are complied with: Conditions as to use of medium pressures

(a) Where a medium pressure supply is used for power purposes or for arc lamps in series:

(1) The frame of every electric motor or transformer shall be efficiently connected with earth.

(2) The wires or conductors forming the connections to the motors, transformers, arc lamps, or otherwise in connection with the supply shall be, as far as practicable, completely inclosed in strong armoring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart or in such a manner that there shall be no danger from fire or shock.

(3) The supply to every motor, transformer, or arc lamp shall be controlled by an efficient switch, placed in such a position as to be easily handled by the person in charge of the motor transformer, or arc lamp, and connected so that by its means all pressure can be cut off from the motor, transformer, or lamp itself, and from any regulating switch, resistance, or other device in connection therewith.

(4) Switches, efficient fuses, or automatic cut-outs shall also be provided, so as to protect the circuits from excess of current, and these switches, fuses, and cut-outs shall be so inclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof or of any fire being caused by their normal or abnormal action.

(b) Where a medium pressure supply is used for incandescent lamps in series:

(1) The wires or conductors forming connections to the incandescent lamps, or otherwise in connection with the supply, shall be completely inclosed in strong armoring or metal casing, and this armoring or casing, together with the switches and lamp holders (if metallic), shall be efficiently connected with earth.

(2) Switches, efficient fuses, or automatic cut-outs shall also be provided, so as to protect the circuits from excess of current, and these switches, fuses, and cut-outs shall be so inclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof or of any fire being caused by their normal or abnormal action.

6. No higher pressure than a medium pressure supply shall be taken beyond the in-by ends of the main air ways. Prohibition of pressure exceeding medium beyond the main airway

7. No higher pressure than a medium pressure supply shall be used other than for transmission or for motors, and then the following conditions shall be complied with: Conditions as to use of high and extra high pressures

(1) No motor or transformer shall be of less normal rating than 75 b. h. p.

(2) The frame of every electric motor or transformer shall be efficiently connected with earth.

(3) The wires or conductors other than overhead lines above ground forming the connections to the motors or transformers or otherwise in connection with the supply shall be completely inclosed in a strong armoring or metal casing efficiently connected with earth.

(4) The machines, apparatus, and lines shall be so marked as to clearly indicate that they are high pressure, either by the use of the word "Danger" at frequent intervals or by vermilion paint properly renewed when necessary.

(5) The motors, machinery coupled thereto, and transformers shall be fixed in proper rooms or inclosures set apart solely for the purpose, and a notice shall be fixed in a conspicuous position at the door of every such room forbidding unauthorized persons to enter.

Test to detect injury to line during installation

8. Every fixed electric line shall be tested for insulation after having been placed in position and before it is used for the purpose of supply, the testing pressure being at least 200 volts. The results of such tests of each line or section of line shall be duly recorded.

Insulation of circuits

9. The insulation of every complete circuit used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit, shall be so maintained that the leakage current shall not under any conditions exceed 1-10,000th of the maximum supply current, and suitable means shall be provided for the immediate localization of leakage.

Special test for circuits above medium pressure before use

10. A high-pressure circuit shall not be brought into use unless the insulation of every part thereof has withstood a continuous application during half an hour of a pressure exceeding the maximum pressure to which it is intended to be subjected in use—that is to say, in the case of every electric line a pressure twice the said maximum pressure, and in the case of every machine device or apparatus a pressure 50 per cent greater than the said maximum pressure. The results of such tests shall be duly recorded.

Earth detectors in generating and transforming stations

11. Earth or fault detectors shall be kept connected up in every generating and transforming station to show immediately any defect in the insulation of the system. The readings of these instruments shall be recorded at least twice daily in a book kept at the generating or transforming station or switch house, and immediate steps shall be taken to rectify any defects.

Construction and arrangement of main and distribution switch and fuse boards

12. Main and distribution switch and fuse boards must be made of incombustible insulating material, such as marble or slate free from metallic veins, and be fixed in as dry a situation as practicable, and be so placed that a fire thereon can not spread to combustible material.

Live metal must be fixed at such a distance from all metal not at the same potential, or be so separated by insulating partitions, that an arc can not be formed between the metal surfaces.

All circuits, switches, and instruments shall be clearly labeled for identification.

Distributing centers and sub-centers

13. Conductors must radiate from distributing centers and in large systems from those centers to subcenters. At these centers suitable switchboards shall be fixed, by which the pressure can be cut off from any circuit.

Bunching of conductors

14. No conductor shall be bunched in the same duct, pipe, or groove with one at another pressure of supply unless they are each separately protected by a strong continuous metallic sheathing efficiently earthed.

Provision of switches, and cut-out or fuse

15. Every circuit carrying not more than 3 amperes must be protected on each pole by a fuse. Every circuit carrying more than 3 amperes must be controlled by a switch on each pole and cut out or fuse on each pole. The switch shall be on the live side of the fuse.

Construction and ventilation of machine rooms

16. No portion of the internal surface of any room in which electrical machinery is installed shall be formed of substances easily ignited, and the use of inflammable materials in such rooms shall be reduced to the minimum. Such rooms when underground shall where possible be ventilated by intake air.

17. Fire buckets, filled with clean dry sand, shall be kept in electrical machine rooms ready for immediate use in extinguishing fires. Fire extinguishing in machine rooms
18. No repair or cleaning of any electrical apparatus except mere wiping or oiling shall be done when the current is on. No repairs to be carried out when current is on
19. Gloves and mats of india rubber or other nonconducting material shall be supplied and used where the live parts of switches or machines working at a pressure exceeding the limits of low pressure have to be handled for the purpose of adjustment. Use of rubber gloves and mats during adjustment of live parts of switches or machines
20. The manager shall appoint a competent person or persons to inspect daily all electrical machinery and apparatus, who shall make a true report in writing of the result of such examination before leaving the mine. Competent person to make daily inspection
21. A competent person shall be on duty at the mine when the electrical apparatus or machinery is in use; and at such time as the amount of electricity delivered down the mine exceeds 200 brake horsepower, a competent person shall be on duty at the mine above ground and another below ground. Competent persons to be on duty
22. No person shall be allowed to work any electrically driven apparatus unless he has been previously instructed in his duty and has been duly authorized by the manager or under-manager. Appointment and instruction of machine attendants
23. All persons engaged in or about the mine shall at once report to the management anything unusual observed in the working of the plant. Immediate report to management of abnormal working of plant
24. No person shall wilfully damage, interfere with, or without proper authority remove or render useless any electric line or any machine, apparatus, or part thereof, used in connection with the supply or use of electricity. Prohibition of unauthorized persons interfering with installation
25. Instructions shall be posted up in every generating and motor house containing directions as to the restoration of persons suffering from electric shock. Posting of instructions as to treatment of persons suffering from electric shock
26. Direct telephonic communication shall be provided—Provision of telephonic communication
 - (a) Between the generating station and the pit bottom or main distributing center in the pit.
 - (b) Between the generating station and the pit head.
 - (c) Between the pit head and the pit bottom or main distributing center in the pit.
27. Before any electric installation is erected at any mine notice in writing must be sent to H. M. inspector of mines for the district. Notice must also be sent of any existing electric installation at any mine within three months after the coming into force of these rules. Notice of existing and new installations to be sent to inspector
28. A plan shall be kept at the mine showing the position of all electrical machinery, apparatus, and lines at or in the mine, and shall be corrected as often as may be necessary to keep it up to a date not more than three months previously. Plan showing installation to be kept
29. If fixed storage batteries are used underground they must be placed in well-ventilated rooms or inclosures. Storage batteries

SECTION II.—Generating stations and machine rooms

1. Generating sets shall be spaced so that there is ample passage all round them, not less than 4 feet between separate sets or less than 3 feet between any set and the wall. Generating sets
- For installations of over 200 brake horsepower an inclosure in which the electrical energy is generated shall be fenced off and set apart for that purpose only. It shall contain the engines, dynamos, switchboards, and any other mechanical or electrical apparatus belonging thereto, but shall not contain boilers, feed pumps, haulage engines, or other machinery, or be used as a storeroom or workshop, except for repairing the machines therein.

Provision of switch house where generating station is over 400 yards from pit mouth

2. Where the generating station under the control of the owner or manager of the mine is not within 400 yards of the pit mouth, a switch house shall be provided near the pit mouth, containing switches for cutting off the supply of electricity to the mine. This house shall only be entered by duly authorized persons, and a notice to that effect shall be posted at the door, and the same regulations as to switchboards and their inclosures in generating stations shall apply thereto.

Main switch-board

3. The main switchboard shall be separated from the engine room by a hard-wood rail not less than 3 feet from the front of the board. The space in front of the board shall be a platform raised not less than 6 inches above the floor level, and preferably constructed of wood blocks.

Provision to be made for clear space at back of main switch-boards

4. If there are any connections at the back of the switchboard, there shall be a clear space behind the board of not less than 3 feet. This space shall not be utilized as a storeroom or a lumber room, or obstructed in any manner by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passageway must be widened accordingly.

No cable shall cross the passage way at the back of the board except below the floor or at a height of not less than 7 feet above the floor.

The space at the back of the switchboards shall be properly floored, accessible from each end and, except in the case of low pressure switchboards, must be kept locked up, but the lock must allow of the door being opened from the inside without the use of a key.

The floor at the back shall be firm and even, and shall be of hard wood, or be covered with good insulating material.

Provision of automatic cut-out and meters for generators

5. Every generator shall be provided with an automatic maximum cut-out or switch and fuse on each pole between the generator and the bus bars.

Where generators are paralleled reverse current cut-outs shall also be provided.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Automatic cut-out and ammeter for feeder circuit

6. Every feeder-circuit shall be provided with an automatic maximum cut-out or switch and fuse on each pole and an ammeter.

Arrangement of switchboard where continuous supply is maintained

7. Where the supply is maintained continuously the switchboards shall be arranged in sections, so that all pressure can be cut off from any section for the purpose of cleaning or repairing it.

No work or cleaning shall be carried out on any portion of a switchboard, above the limits of low pressure, while the pressure is on the board.

Lightning arresters for overhead lines

8. If the transmission lines from the generating station to the pit are overhead there shall be lightning arresters in connection with the feeder circuits.

Protection from short circuits with low pressure installations

9. Where the supply is at low pressure the bus bars and any live metal work on the front of the boards must be so spaced or separated by fillets of nonconducting material that there shall be no danger of accidental short circuits, and switches must be provided which will open even on a short circuit without danger to the attendant.

Automatic cut-outs must be arranged so that when opening outwards the contact lever does not fall within 6 feet 6 inches of the floor. If uninclosed fuses are used they must be placed within 2 feet of the floor.

Live metal on front of switchboards at medium pressure and upwards

10. Where the supply is at a pressure exceeding the limits of low pressure, there shall be no live metal work on the front of the switchboard within 8 ft. of the platform and the space provided under rule 4 shall be not less than 4 ft. in the clear.

High pressure meters to be connected through transformers where practicable

11. Where the supply is at a pressure exceeding the limits of medium pressure the instruments should, where practicable, be connected through transformers and worked at low pressure. Where such transformers are not used the metal cases of all instruments shall be either earthed and guarded by efficient earthed metal cages out of reach of the attendant, or be completely protected with insulating covers.

Metal casings, etc., to be earthed

All metal work not in connection with the circuits shall be connected to earth, and all switches shall be operated by long and well insulated levers.

12. The frames and bedplates of all generating machines and transformers at a pressure exceeding the limits of low pressure shall be efficiently connected to earth. Earthing of machine frames
13. All terminals and live metal work, where practicable, shall be protected with insulating covers or with metal covers connected to earth. Protection of live metal
- The brush rockers of machines working at a pressure exceeding the limits of low pressure shall be worked by hand wheels at a safe distance from the brushes. Brush rockers
14. Insulating stands or rubber mats must be placed at the commutator or collector side of all open type machines working at a pressure exceeding the limits of low pressure. Rubber mats
15. The fencing of generators having collector rings or commutators must be of teak or hard wood or metal. If of metal, that part of the metal which might be touched by a person when wiping commutator or collector rings shall be covered with insulating material. Fencing of generators
16. No person other than an authorized person shall enter a machine or motor room or interfere with the working of any machine, motor, or apparatus connected therewith. Unauthorized persons not to enter motor rooms or interfere with apparatus

SECTION III.—Cables

1. Except as hereinafter provided, metallic circuits shall in every case be maintained completely insulated from earth. Prohibition of earthed circuits
- The neutral point of polyphase systems shall not be earthed without notification in writing to the inspector of mines of the district.
2. All continuously insulated cables and wires shall be highly insulated, and the insulating material must be protected from mechanical injury. Insulation of continuously insulated cables
- The insulating material must be so protected or, as far as is practicable, be of itself of such a nature that it will not deteriorate under the action of water or alternate periods of wet and dry, or at the highest temperature to which it will be subjected. Rubber must not be allowed to exceed 130° F., or paper or fiber insulation 170° F. In specially hot places the conductors shall be so large that the electric heating is almost nil.
3. A continuously insulated cable must be so constructed that when a test piece of it has been immersed in water for twenty-four hours it will, while still immersed, in the case of cables intended for low or medium pressures, withstand 2,000 volts for ten minutes between the conductor and the water, and between cores if there are more than one in the cable. Tests of continuously insulated cables
- If the cable is intended for high or extra high pressure twice the working pressure shall be taken for this test.
- Prior to the immersion the test piece must have been bent six times (three times in one direction and three times in the opposite direction) round a cylindrical surface not more than twelve times the diameter of the finished cable.
4. Continuously insulated cables and wires which are to be used at low and medium pressures must be subjected at the maker's works to a test under water of 2,000 volts for one hour between the conductor and the water, and between cores if there are more than one in the cable, after twenty-four hours' immersion in water, and each drum and coil must be certified to have been so tested. Certificate of maker's tests
- Where high or extra high working pressures are intended the tests must be made at twice the working pressure.
- A written certificate signed by a cable manufacturer or competent engineer of the United Kingdom shall be sufficient evidence that the requirements of this rule have been complied with.
5. Unless fixed in sight and out of reach of injury, all conductors other than lead covered armored cables must further be protected by a strong covering, and this in damp situations must consist of water-tight metal tubes, which shall be electrically continuous throughout, and efficiently connected to earth. Means must be provided to prevent the accumulation within the tubing of water arising from condensation or Protection of conductors

other sources. Short bends or elbows must be avoided, corners being turned by smoothbore round bends or suitable boxes.

Protection of exposed ends of conductors entering terminals of switches, etc.

6. The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances, must be properly protected and finished off, so that moisture can not creep along the insulating material within the waterproof sheath, nor can the insulating material, if of an oily nature, leak out of the cable.

Limits of sections

7. The sectional area of a copper conductor must not be less than that of a No. 18 S. W. G. wire, with the exception of the case of flexible cord conductors and wires for fittings, when the sectional area must not be less than that of a No. 20 S. W. G. wire. All insulated copper conductors having a greater area than that of a No. 14 S. W. G. wire must be stranded.

Sectional area of conductors

8. The section of all conductors along which the current is to pass shall be such that if double the normal current were flowing the temperature would not rise to the point at which the insulating material would be damaged or deteriorated.

Current densities

9. If the conductors are of copper they shall be of high conductivity, and when the area does not exceed .2 square inches the current density must not exceed 1,000 amperes per square inch; when the area exceeds .2 square inches, but does not exceed .7 square inches, the current density must not exceed 800 amperes per square inch; and when the area exceeds .7 square inches, but does not exceed 1 square inch, the current density must not exceed 750 amperes per square inch.

Joints not to take strain

10. In every case wires and cables must be so clamped and secured at their joints as to insure that the contact is relieved not only from the weight of the cables, but from any strain that may be put upon them.

Joints

11. All joints must be, as far as practicable, mechanically and electrically perfect to prevent heat being generated. All joints where possible must be soldered. Soldering fluids containing acids or other corrosive substances must not be used. The insulation of all joints in insulated conductors must be most carefully attended to. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, suitable joint boxes must be used.

Joint boxes

12. Joint boxes must be used to connect lengths of cables or conductors equivalent to, or larger than 7-16 S. W. G., and must be so constructed that—

- (a) The conductors can not be readily short-circuited;
- (b) The insulation between opposite poles will not readily break or chip;
- (c) The connections do not heat.

If used in damp places special precautions must be adopted to exclude moisture.

Joints constitute a source of weakness, and they must therefore be accessible, and their positions should be indicated by a conspicuous mark.

Joining of cables in certain places

13. Soldering of joints is prohibited in any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies. In such places conductors must be connected by means of metal screw clamps, connectors, or their equivalent. These connectors must consist of separate clamps on each cable end, with a gap between, which must be bridged across by a link making contact under oil, or in a gas-tight box. The links should be easily removable for dividing the cables when required for testing purposes.

The connectors must be constructed with ample contact surface to prevent any perceptible rise of temperature when carrying twice the full load.

When the separate conductors of cables, at different potentials, such as twin, triple, or concentric cables, are connected in the same box, ample insulation and mechanical protection must be provided between the conductors. On no account may wires, other than signaling wires, or cables be joined by merely twisting them together.

Overhead lines on surface

14. It shall be permissible to use on the surface bare overhead wires under the following conditions:

- (a) Every overhead line shall be attached to supports at intervals not exceeding 200 feet where the direction of the line is straight, or 150 feet where the line makes an angle at the point of support.

(b) Every support for an overhead line shall be of durable material, and properly stayed to withstand forces due to wind pressure, change of direction, or unequal lengths of span, and have a factor of safety of at least ten, calculated from the weight of the wires only. The wires must have a factor of safety of at least five at 32° F.

(c) All overhead lines shall be attached to insulators, and shall be so guarded that they can not fall away from the supports.

(d) The overhead lines shall at every part be absolutely clear of any traffic going under them.

(e) Whenever overhead lines are used they must be protected by efficient lightning arrestors.

(f) Service lines from overhead lines shall be connected as directly as possible to suitable insulators firmly attached to some portion of the premises which is not accessible to any person without the use of a ladder, and from this point they shall be efficiently inclosed and protected.

15. Cables buried on the surface shall be continuously insulated.

Buried lines
on surface

Unarmored cables must be mechanically protected by suitable material. High tension cables must not be placed in the same trough or conduit with low or medium tension cables, unless they are each separately protected by earthed metallic shields.

16. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables shall be properly supported at intervals, varying according to the weight of the cable. Where the cables are not completely boxed in and protected from falling material, space should be left between them and the side of the shaft that they may yield, and so lessen a blow given by falling material. They shall, if reasonably practicable, be taken down the down-cast shaft and along the main intake air ways.

Shaft cables

17. (a) As the condition of underground roads is very variable, the manager shall be responsible for placing the cables in positions where they will be least liable to be damaged by falls of roofs or sides, or by tubs or trams passing or getting off the road.

Underground
cables

(b) Where the cables in main haulage roads can not be kept at least 1 foot from any part of the tub or tram, they shall be specially protected. When single cables are used they shall, if practicable, be fixed on opposite sides of the road.

(c) The fixing with metallic fastenings of cables and wires not provided with metallic covering to walls or timbers is prohibited.

(d) Cables when suspended shall be suspended by leather or other flexible material in such a manner as to allow of their readily breaking away when struck, before the cables themselves can be seriously damaged.

(e) Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with either galvanized steel wire armoring, extra stout braiding, hose pipe, or other effective covering. Trailing cables shall be regularly inspected, and any defects in them promptly repaired.

(f) At points where the flexible conductors are joined to the main cables, a fixed terminal box must be provided, and be of such design that the lugs can be securely clamped without risk of undue heating, and that no live metal can be exposed when the lid is closed. A switch shall be fixed close to or in the terminal box capable of entirely cutting off the supply from the terminal box and motor.

18. Where main or other roads are being repaired, or blasting is being carried out, suitable temporary protection must be used so that the cables can not be damaged.

Cables to be
protected during
repair of roads or
blasting

SECTION IV.—Switches, fuses, and cut-outs

1. Every switch must be of such a type and size that it will not overheat when the full current flows continuously; when it is switched off under full load it must not be possible to form an arc, and it must be incapable of remaining in partial contact, and its handle must be insulated and so arranged that the hand can not touch live metal.

Switches to be
of suitable design

- Fuses to be of suitable design** 2. Fuses must be so proportioned that no overheating can take place in any part when the full current flows continuously. They shall effectually interrupt the current when a short circuit occurs, and also when the current through them exceeds the working current by 100 per cent. Their covers must be of incombustible material, and either nonconducting or of rigid metal lined with insulating incombustible material, and kept clear of all internal mechanism. Fuses must not be placed in wall sockets, ceiling roses, or switch covers.
- Material, marking and re-placing of fuses** 3. Hard metal or soft metal soldered to hard metal lugs must be used for fuses. They shall be stamped or marked with the current for which they are intended to be used, and shall only be changed or replaced by an authorized person. In the event of a fuse melting, its circuit must be switched off before the fuse is replaced.
- Inclosure of switches, fuses, etc., not in machine rooms** 4. All live parts of switches, fuses, and cut-outs not in machine rooms, or in compartments specially arranged for the purpose, must be covered. These covers must be of incombustible material, and must be either nonconducting or of rigid metal, and, as far as practicable, clear of all internal mechanism.
- Makeshift switches not permissible** 5. All points at which the circuit has to be made or broken shall be fitted with proper switches. The use of hooks or other makeshifts is prohibited.
- Prohibition of open type switches and fuses in certain places** 6. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, the use of open type switches, fuses, and cut-outs is prohibited; they must either be inclosed in gas-tight boxes, or break under oil.

SECTION V.—Motors

- Switches to be placed near motors** 1. All motors, together with their starting resistances, shall be protected by switches capable of entirely cutting off the pressure, and fixed in a convenient position near the motor.
- Ammeter for each motor** 2. Every motor in a machine room shall be provided with a suitable ammeter to indicate the load put upon the machine.
- Motors to be worked without undue heating** 3. Motors must not be worked at a heavier load than they can carry for a six hours run, with a maximum rise of temperature attained by any accessible part of the motor of 80° F. as measured by a thermometer.
- Protection for cables passing through metal casings, etc.** 4. Special care must be taken to insure that the holes, where unarmored cables or wires pass through metal frames or into boxes or motor casings, are substantially bushed with insulating bushes, and, where necessary, with gas-tight bushings, which can not readily become displaced. All the internal machine connections shall be efficiently protected against damage by accident or rough usage.
- Provision of flame-tight inclosure of motors, etc., in certain places, which are only to be opened by authorized persons** 5. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current carrying parts, also their starters, terminals, and connections, completely inclosed in flame-tight inclosures, made of unflammable material, and of sufficient strength as not to be liable to be damaged should an explosion of fire damp occur in the interior, and such inclosure shall not be opened except by an authorized person, and then only when the current is switched off. The pressure shall not be switched on while the inclosures are open.
- Current to be switched on gradually** 6. When starting a motor the switch block shall not be moved across the contacts with one rapid movement, but with a slow movement until the armature has attained its proper speed, and care must be taken that the strain is put on the machine gradually.
- Inclosure of portable motors** 7. Portable motors which are fed by flexible cables must be provided with strong terminal boxes for making secure mechanical and electrical contact with the cable lugs, as provided in Sec. III., rule 17 (f); the boxes must entirely inclose all live metal, and the lids must be firmly screwed down. These boxes must be securely attached to the machines, or be designed to form a part thereof.

8. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, a safety lamp or other suitable apparatus for the detection of fire damp shall be provided for use with each machine when working, and, should any indication of fire damp appear on the flame of the safety lamp or other apparatus used for the detection of fire damp, the person in charge shall immediately stop the machine, cut off the current at the gate end or nearest switch, and report the matter to an official of the mine.

Motors to cease working if fire damp is present

9. In cases where the cutter of a coal-cutting machine becomes jammed, the current shall be immediately cut off from the motor, and the tension holding the machine up to the face shall be released. The machine shall not be re-started until the increased load upon the cutter has been removed.

Current to be cut off at motor if machine is jammed

10. A coal-cutter motor shall not be kept continuously at work for a period of time exceeding a maximum period, which shall be specified in writing by the manager.

Manager to specify length of period of continuous work of coal-cutter

11. The casing of all portable motors shall at least once a week be opened by a competent person appointed by the manager, and the parts of the motor so inclosed shall be cleaned, and all dust and dirt be removed before the casing is replaced.

Casing of portable motors to be opened once a week

12. All portable machines, when in use, and their trailing cables, with switches, fuses, and other appliances, shall once in every twenty-four hours be examined by a competent person or persons appointed by the manager.

Daily examination of portable machinery and accessories

13. The person in charge of a coal-cutter or drilling machine shall be a thoroughly competent man duly authorized by the manager; he shall not leave the machine while it is working, and shall, before leaving the working place, see that the current is cut off from the trailing cables. He must not allow the cables to be dragged along by the machine.

Authorized person to be in charge of portable machines

Current to be cut off at close of work

14. No repairs shall be made to any portable machine until the pressure has been cut off from the trailing cables.

No repairs to portable machines while current is on

15. Should any sparking or arc be produced outside a coal-cutting or other portable machine, or by the cables or rails, the machine shall be stopped, and the occurrence reported to an official of the mine, and the machine shall not be worked again until the defect is repaired.

Portable machines to cease working when out of order

16. Wedges or blocks shall be systematically inserted into the holing cut as the cutter progresses, and at a distance apart to be fixed by the manager. Where the holings left by the machine are found to be sufficient to act in place of wedges, wedges need not be inserted.

Manager to fix interval between wedges in holing

SECTION VI.—Electric locomotives

1. Electric haulage by locomotives by the trolley system is not permissible in any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies. On this system no pressure exceeding the limits of medium pressure may be employed.

Electric locomotives only permissible in certain places and then with medium and low pressures only

2. The cab of the locomotive and all trucks used to convey persons shall be so roofed that persons riding are efficiently screened from contact either with the trolley wires or the roof of the road.

Protection from danger of stock

3. In drifts and underground roads the trolley wires must be placed so that they are at least 7 feet above the level of the road or track, or the pressure must be cut off from the wires during such hours as the roads are used for traveling on foot. The hours during which traveling on foot is permitted shall be clearly indicated by notices and signals placed in a conspicuous position at the ends of the roads. At other times no one other than a duly authorized person shall be permitted to travel on foot along the road.

Position of trolley wires and conditions of working

4. On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

System of returns

Separate generator to be employed for locomotives

5. In order to prevent any other part of the system being earthed, the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from or be in connection with electric lines used for any other purpose.

Protection of storage battery locomotives in certain mines

6. If storage battery locomotives are used in any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

SECTION VII.—*Electric lighting*

Lampholders, switches, etc., not to be directly fixed to metal or timbering.

1. Lampholders, switches, or other fittings must not be directly fixed to the timbering or metal work, but to hard wood, or incombustible, nonhygroscopic, insulating base blocks.

Use of arc lamps

2. All arc lamps shall be so guarded as to prevent pieces of ignited carbon or broken glass falling from them, and shall not be used in situations where there is any danger from the presence of coal dust. They shall be so screened as to prevent risk of contact with persons.

Pressure for lighting

3. For lighting purposes only low pressure electricity shall be used, unless the conditions set out in rule 5, Section I, are complied with.

System of wiring

4. Small wires for lighting circuits must be either conveyed in pipes or casings, which, if underground, shall be noninflammable, or suspended from porcelain insulators, or tied to them with some nonconducting material which will not cut the covering, and so that they do not touch any timbering or metal work. On no account must staples be used. If metallic pipes are used they must be electrically continuous and earthed. If separate uncased wires are used they must be kept at least 2 inches apart, and not brought together except at lamps or switches or fittings.

Wires not to be subjected to mechanical strain

5. No wire carrying a current shall be used underground to support a lamp, or be otherwise subjected to mechanical strain.

Vacuum lamps only permissible in certain places

6. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, vacuum lamps must alone be used; they shall be inclosed in gas-tight fittings of strong glass, and have no flexible cord connections. The wires must be protected by a strong continuous metallic sheathing efficiently earthed.

Lamps to be changed only by authorized persons and when current is off in certain places

7. Lamps underground shall only be changed by a duly authorized competent person. While lamps are being changed on any circuit in any place or part of a mine as mentioned in rule 6, the supply must be switched off from that circuit.

Other lights to be provided at certain places in case of failure of electric light

8. At every entrance between the top and bottom of the shaft and at the shaft bottom, and in all machine rooms and at other places, where the failure of electric light is likely to cause danger, a sufficient supply of safety lamps or other suitable lights shall be maintained for use in the event of a failure of the electric light.

SECTION VIII.—*Shot firing*

Shots to be fired electrically in places to which the explosives in coal mines orders apply

1. All shots in places to which the explosives in coal mines orders apply shall be fired by electricity, and only by such persons as are duly authorized in writing. High tension magneto-generators shall be inclosed in flame-tight cases when used in such mines.

Firing cable to be not less than 25 yards in length

2. The shot-firing cable shall be of such length as to enable the shot firer to be out of danger from projected material, and shall in no case be of less length than 25 yards.

Method of connecting up for firing

3. The shot-firing cable shall be first connected to the detonator or fuse wire by the shot firer, and not connected to the electric firing apparatus until all persons in the vicinity have taken cover.

4. The handle or key of a magneto shot-firing apparatus shall be detached when not required for firing, and shall under no conditions pass from the personal custody of the shot firer whilst on duty. Magneto machines must be frequently tested to insure that they give the necessary pressure and current. Detachable key or plug of magneto generators to be in custody of shot-firer

Primary or secondary batteries when used for shot firing shall be provided with a removable connecting plug or key, without which the circuit can not be closed, and this plug or key shall be detached when not required for firing, and shall under no conditions pass from the personal custody of the shot firer whilst on duty. Such batteries must be frequently tested to insure that they give the necessary pressure and current. Detachable plug of cell batteries to be in custody of shot firer. Batteries to be tested for efficiency

6. Electricity from lighting or power cables shall not be used for firing shots, except in sinking shafts or stone drifts, and then only when a special firing plug, button, or switch is provided, which plug, button, or switch shall be placed in a fixed locked box, and shall only be accessible to the authorized shot firer. Electricity from light or power mains not to be used except under certain conditions and then only in sinking shafts, etc.

The firing cable or wires shall not be connected to this box until immediately before it is required for the firing of shots, and shall be disconnected immediately after the shots are fired.

7. No person shall approach a shot which has been attempted to be fired by electricity and failed to explode until the firing cable or wires have been disconnected from the apparatus. Cable to be disconnected before any person approaches missed shot

8. When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables. Firing cable not to be in contact with other cables

SECTION IX.—*Signaling*

1. All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not. Signal wires not to come into contact with other wires

2. Contact makers or push buttons of electric signaling circuits shall be so constructed and placed as to prevent the circuit being accidentally closed. Prevention of circuit being accidentally closed

3. In any place or part of a mine to which general rule No. 8 of the coal mines regulation act, 1887, applies, bare wires shall not be used for signaling circuits except in haulage roads, and the pressure shall not exceed 10 volts in any one circuit. If the length of line would otherwise necessitate a higher pressure, suitable relays must be provided. Limit of pressure where bare wires are used, in certain places

SECTION X.—*Electric relighting of safety lamps*

1. In mines to any place or part of which general rule No. 8 of the coal mines regulation act, 1887, applies, when safety lamps are relighted underground by electricity, the manager shall select a suitable station or stations, which are not in the return airway, and in which there is not likely to be any accumulation of inflammable gas; and no electric relighting apparatus shall be used in any other place. The relighting apparatus shall be securely locked so as not to be available for use except by persons authorized by the manager to relight safety lamps, and who shall examine all safety lamps brought for relighting before they are reissued. Authorized person to be in charge of relighting apparatus, and to examine lamps before release in certain mines

2. All such apparatus shall be inclosed in a flame-tight casing, and shall be provided with a suitable switch or safety plug so that no sparking can occur except between the terminals provided for the purpose inside the safety lamp. Apparatus to be inclosed in flame-tight case

SECTION XI.—*Exemptions and miscellaneous*

1. Notwithstanding anything contained in these rules, any electrical works or apparatus installed or in use before the coming into force of these rules may be continued in use unless an inspector shall otherwise direct or subject to any conditions that he may prescribe. Exemption for existing installations with inspector's leave

Exemption from
rules in special
cases

2. An inspector may by writing, signed by him, dispense with any of the above rules in any case in which the special circumstances appear to him to render such exemption necessary or desirable.

Sec. 42 of C. M.
R. A., and sec.
18 of M. M. R. A.

3. In case any difference of opinion shall arise between an inspector and an owner as to any requirement or exception under this section, the same shall be settled as provided in section 42 of the coal mines regulation act, 1887, or in section 18 of the metalliferous mines regulation act, 1872.

The foregoing proposed set of rules was considerably modified and the following code was put into effect by the British Home Office in 1905:

SPECIAL RULES FOR THE INSTALLATION AND USE OF ELECTRICITY IN MINES

DEFINITIONS

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth as read by a hot wire or electrostatic voltmeter, and

(a) Where the conditions of the supply are such that the pressure at the terminals where the electricity is used can not exceed 250 volts, the supply shall be deemed a low-pressure supply.

(b) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250 volts, but can not exceed 650 volts, the supply shall be deemed a medium-pressure supply.

(c) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 650 volts, but can not exceed 3,000 volts, the supply shall be deemed a high-pressure supply.

(d) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts, the supply shall be deemed an extra high-pressure supply.

SECTION I.—General

1. (a) All electrical apparatus and conductors shall be sufficient in size and power for the work they may be called upon to do, and, so far as is reasonably practicable, efficiently covered or safeguarded, and so installed, worked, and maintained as to reduce the danger through accidental shock or fire to the minimum, and shall be of such construction, and so worked that the rise in temperature caused by ordinary working will not injure the insulating materials.

(b) In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, the covering shall be constructed so that, as far as is reasonably practicable, there is no danger of firing gas by sparking or flashing which may occur during the normal or abnormal working of the apparatus.

(c) All metallic coverings, armoring of cables, other than trailing cables, and the frames and bedplates of generators, transformers, and motors other than portable motors, shall, as far as is reasonably practicable, be efficiently earthed where the pressure at the terminals where the electricity is used exceeds the limits of low pressure.

2. Where a medium-pressure supply is used for power purposes, or for arc lamps in series, the wires or conductors forming the connections to the motors, transformers, arc lamps, or otherwise in connection with the supply, shall be, as far as is reasonably practicable, completely inclosed in strong armoring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner

that danger from fire or shock may be reduced to a minimum. This rule shall not apply to trailing cables.

3. Where a medium-pressure supply is used for incandescent lamps in series, the wires or conductors forming connections to the incandescent lamps, or otherwise in connection with the supply, shall be, as far as is reasonably practicable, completely inclosed in strong armoring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart or in such a manner that danger from fire or shock shall be reduced to the minimum.

4. Motors of coal cutting and such other portable machines shall not be used at a pressure higher than medium pressure. No transformer used for supplying current at a pressure higher than medium pressure, and no motor using such current shall be of less normal rating than 20 b. h. p. for use underground.

No higher pressure than a medium pressure shall be used in any place or any part of the mine to which the general rule No. 8 of the coal mines regulation act, 1887, applies.

5. No higher pressure than a medium-pressure supply shall be used other than for transmission or for motors, and the wires or conductors other than overhead lines above ground forming the connections to the motors or transformers or otherwise in connection with the supply shall be completely inclosed in a strong armoring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart or in such a manner that danger from fire or shock shall be reduced to the minimum.

The machines, apparatus, and lines shall be so marked as to clearly indicate that they are high pressure, either by the use of the word "Danger" at frequent intervals or by red paint properly renewed when necessary.

6. The insulation of every complete circuit other than telephone or signal wires used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current, and suitable means shall be provided for the immediate localization of leakage.

7. In every completely insulated circuit earth or fault detectors shall be connected up in every generating and transforming station to show immediately any defect in the insulation of the system. The readings of these instruments shall be recorded daily in a book kept at the generating or transforming station or switch house.

8. Main and distribution switch and fuse boards must be made of incombustible insulating material, such as marble or slate, free from metallic veins, and be fixed in as dry a situation as practicable.

9. Every subcircuit must be protected by a fuse on each pole. Every circuit carrying more than 5 amperes up to 125 volts or 3 amperes at any pressure above 125 volts must be protected in one of the following alternative methods:

(a) By an automatic maximum cut-out on each pole.

(b) By a detachable fuse on each pole, constructed in such a manner that it can be removed from a live circuit with the minimum risk of shock.

(c) By a switch and fuse on each pole.

10. Fire buckets filled with clean, dry sand shall be kept in electrical machine rooms ready for immediate use in extinguishing fires.

No repair or cleaning of the live parts of any electrical apparatus except mere wiping or oiling shall be done when the current is on.

Gloves, mats, or shoes, of india rubber or other nonconducting material, shall be supplied and used where the live parts of switches or machines, working at a pressure exceeding the limits of low pressure, have to be handled for the purpose of adjustment.

11. A competent person shall be on duty at the mine when the electrical apparatus or machinery is in use, and at such time as the amount of electricity delivered down the mine exceeds 200 b. h. p. a competent person shall be on duty at the mine above ground and another below ground. Every person appointed to work any electric apparatus shall have been instructed in his duty and be competent for the work that he is set to do.

12. No person shall wilfully damage, interfere with, or without proper authority remove or render useless any electric line or any machine, apparatus or part thereof, used in connection with the supply or use of electricity.

13. Instructions shall be posted up in every generating, transforming, and motor house containing directions as to the restoration of persons suffering from electric shock.

14. Direct telephonic or other equivalent means of communication shall be provided between the surface and the pit bottom or main distributing center in the pit.

15. Within three months after the introduction into any mine of electric motive power, notice in writing must be sent to His Majesty's inspector of mines for the district. Notice must also be sent of any existing electric motive power installation at any mine within three months after the coming into force of these rules.

16. A plan shall be kept at the mine showing the position of all permanent electrical machinery and cables in the mine, and shall be corrected as often as may be necessary to keep it up to a date not more than three months previously.

SECTION II.—*Generating stations and machine rooms*

1. Where the generating station under the control of the owner or manager of the mine is not within 400 yards of the working pit mouth, an efficiently inclosed locked switch box or boxes, or a switch house shall, where reasonably practicable, be provided near the pit mouth for cutting off the supply of electricity to the mine.

2. There shall be a passageway in front of the switchboard of not less than 3 feet in width, and if there are any connections at the back of the switchboard, any passageway behind the switchboard shall not be less than 3 feet clear. This space shall not be utilized as a storeroom or a lumber room, or obstructed in any manner by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passageway must be widened accordingly.

No cable shall cross the passageway at the back of the board except below the floor, or at a height of not less than 7 feet above the floor.

The space at the back of the switchboards shall be properly floored, accessible from each end, and, except in the case of low-pressure switchboards, must be kept locked up, but the lock must allow of the door being opened from the inside without the use of a key. The floor at the back shall be incombustible, firm, and even.

3. Every generator shall be provided with a switch on each pole between the generator and the bus bars.

Where continuous-current generators are paralleled, reversed current cut-outs shall be provided.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Every feeder circuit shall at its origin be provided with an ammeter.

4. If the transmission lines from the generating station to the pit are overhead, there shall be lightning arresters in connection with the feeder circuits.

5. Automatic cut-outs must be arranged so that when the contact lever opens outward no danger exists of striking the head of the attendant. If uninclosed fuses are used, they must be placed within 2 feet of the floor or be otherwise suitably protected.

Where the supply is at a pressure exceeding the limits of medium pressure, there shall be no live metal work on the front of the main switchboard within 8 feet of the

floor or platform, and the space provided under rule No. 2 of this section shall be not less than 4 feet in the clear. Insulating floors or mats shall be provided for medium-pressure boards where live metal work is on the front or back.

6. All terminals and live metal on machines over medium pressure above ground, and over low pressure underground, where practicable, shall be protected with insulating covers or with metal covers connected to earth.

7. No person other than an authorized person shall enter a machine or motor room, or interfere with the working of any machine, motor, or apparatus connected therewith.

SECTION III.—*Cables*

1. All conductors (except as hereinafter provided) shall in every case be maintained completely insulated from earth, but it is permissible to use the concentric system with earthed outer conductor, if proper arrangements are made to reduce the danger from fire or shock to the minimum, but the neutral point of polyphase systems and the middle wire of 3-wire continuous-current systems may be earthed at one point.

2. Unless fixed as far as is reasonably practicable out of reach of injury, all conductors, other than armored cables, must further be protected by a suitable covering. Where lead-covered cable is used the lead shall be earthed and electrically continuous throughout.

The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances must as far as is reasonably practicable be properly protected and finished off, so that moisture can not creep along the insulating material within the waterproof sheet, nor can the insulating material, if of an oily nature, leak out of the cable.

3. All joints must be mechanically and electrically efficient, and, where reasonably practicable, must be suitably soldered. In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, suitable joint boxes must be used, and the conductors connected by means of metal screw clamps, connectors, or their equivalent, constructed in a safe manner. Provided, that in any place or part of a mine where a shot may be fired, joints may be soldered by or in the presence of a person authorized in that behalf by the manager, but the same precautions in regard to examination and removal of workmen as are prescribed by paragraphs (f) and (i) of general rule No. 12 shall be observed in all cases, and where the place is dry and dusty, also the precautions as to watering prescribed by paragraph (h). Wires, other than signaling wires or cables, must not be joined by merely twisting them together.

4. Overhead bare wires on the surface must be efficiently supported upon insulators and clear of any traffic, and provided with efficient lightning arresters.

5. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables, not capable of sustaining their own weight, shall be properly supported at intervals, varying according to the weight of the cable. Where the cables are not completely boxed in and protected from falling material, space shall be left between them and the side of the shaft that they may yield, and so lessen a blow given by falling material.

6. Where the cables in main haulage roads can not be kept at least 1 foot from any part of the tub or tram, they shall be specially protected. When separate cables are used they shall, if reasonably practicable, be fixed on opposite sides of the road.

The fixing with metallic fastenings of cables and wires not provided with metallic covering to walls or timbers is prohibited.

Cables underground, when suspended, shall be suspended by leather or other flexible material in such a manner as to allow of their readily breaking away when struck before the cables themselves can be seriously damaged.

Where main or other roads are being repaired or blasting is being carried out, suitable temporary protection must be used so that the cables are reasonably protected from damage.

7. Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with either galvanized steel wire armoring, extra stout braiding, hose pipe, or other effective covering. Trailing cables shall be examined at least once in each shift by the person in charge of the machine and any defects in them promptly repaired.

At points where the flexible conductors are joined to the main cables a fixed terminal box must be provided, and a switch shall be fixed close to or in the terminal box capable of entirely cutting off the supply from the terminal box and motor.

SECTION IV.—*Switches, fuses, and cut-outs*

1. Fuses and automatic cut-outs shall be so constructed as effectually to interrupt the current when a short circuit occurs or when the current through them exceeds the working current by 200 per cent. Fuses shall be stamped or marked or shall have a label attached indicating the current with which they are intended to be used, or where fuse wire is used each coil in use shall be so stamped or labeled. Fuses shall only be adjusted or replaced by an authorized person.

2. All live parts of switches, fuses, and cut-outs not in machine rooms, or in compartments specially arranged for the purpose must be covered. These covers must be of incombustible material and must be either nonconducting or of rigid metal and, as far as practicable, clear of all internal mechanism.

3. All points at which a circuit other than those for signals has to be made or broken shall be fitted with proper switches. The use of hooks or other makeshifts is prohibited, and in any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, the use of open-type switches, fuses, and cut-outs is prohibited. They must entirely be inclosed in gas-tight boxes or break under oil.

SECTION V.—*Motors*

1. All motors, together with their starting resistances, shall be protected by switches capable of entirely cutting off the pressure, and fixed in a convenient position near the motor and every motor of 10-horsepower or over in a machine room underground shall be provided with a suitable ammeter to indicate the load put upon the machine.

2. Where unarmored cables or wires pass through metal frames or into boxes or motor casings, the holes must be substantially bushed with insulating bushes, and where necessary, with gas-tight bushings which can not readily become displaced.

3. Terminal boxes of portable motors must be securely attached to the machine, or be designed to form a part thereof.

4. In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current-carrying parts, also their starters, terminals, and connections completely inclosed in flame-tight inclosures, made of unflammable material and of sufficient strength as not to be liable to be damaged should an explosion of fire damp occur in the interior, and such inclosures shall not be opened except by an authorized person, and then only when the current is switched off. The pressure shall not be switched on while the inclosures are open.

5. In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, a safety lamp or other suitable apparatus for the detection of fire damp shall be provided for use with each machine when working, and should any indication of fire damp appear on the flame of the safety lamp or other apparatus used for the detection of fire damp, the person in charge shall immediately stop the machine, cut off the current at the gate end or nearest switch, and report the matter to an official of the mine.

6. (a) A coal-cutter motor shall not be kept continuously at work for a period of time exceeding a maximum period which shall be specified in writing by the manager, so that the roof may be carefully examined.

(b) The casing or inspection doors of all portable motors used underground and the casings of their switches and other appliances shall at least once a week be opened by a competent person appointed by the manager, and the parts so disclosed shall be cleaned and examined before the coverings are replaced. In special cases requiring a motor to run continuously longer than one week, the motor shall be examined at the end of the run. A report of such examination shall be entered in a report book.

7. The person in charge of a coal-cutter or drilling machine shall not leave the machine while it is working, and shall, before leaving the working place, see that the current is cut off from the trailing cables. He must not allow the cables to be dragged along by the machine. No repairs shall be made to any portable machine until the pressure has been cut off from the trailing cables.

8. If any electric sparking or arc be produced outside a coal-cutting or other portable motor or by the cables or rails, the machine shall be stopped, and not be worked again until the defect is repaired, and the occurrence shall be reported to an official of the mine.

SECTION VI.—*Electric locomotives*

1. Electric haulage by locomotives by the trolley-wire system is not permissible in any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies. On this system no pressure exceeding the limits of medium pressure may be employed.

2. In underground roads the trolley wires must be placed so that they are at least 7 feet above the level of the road or track, or elsewhere, if sufficiently guarded, or the pressure must be cut off from the wires during such hours as the roads are used for traveling on foot in places where trolley wires are fixed. The hours during which traveling on foot is permitted shall be clearly indicated by notices and signals placed in a conspicuous position at the ends of the roads. At other times no one other than a duly authorized person shall be permitted to travel on foot along the road.

On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

3. In order to prevent any other part of the system being earthed (except when the concentric system with earthed outer conductor is used) the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from or be in connection with electric lines otherwise completely insulated from earth.

4. If storage-battery locomotives are used in any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

SECTION VII.—*Electric lighting*

1. All arc lamps shall be so guarded as to prevent pieces of ignited carbon falling from them, and shall not be used in situations where there is likely to be danger from the presence of coal dust. They should be so screened as to prevent risk of contact with persons.

2. Small wires for lighting circuits must be either conveyed in pipes or casings, or suspended from porcelain insulators, or tied to them with some nonconducting material which will not cut the covering and so that they do not touch any timbering or metal work. On no account must staples be used. If metallic pipes are used, they must be electrically continuous and earthed. If separate uncased wires are used, they must be kept at least 2 inches apart and not brought together except at lamps or switches or fittings.

3. In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, electrical lamps, if used, must be of the vacuum or inclosed type; they shall be protected by gas-tight fittings of strong glass, and have no flexible cord connections, and shall only be changed by a duly authorized competent person. While the lamps are being changed the current shall be switched off.

4. In all machine rooms and other places underground where a failure of electric light is likely to cause danger, some safety lamps, or other proper lights, shall be kept for use in the event of such failure.

SECTION VIII.—*Shot firing*

1. Electricity from lighting or power cables shall not be used for firing shots, except in sinking shafts or stone drifts, and then only when a special firing plug, button, or switch is provided, which plug, button, or switch shall be placed in a fixed locked box, and shall only be accessible to the authorized shot firer.

The firing cables or wires shall not be connected to this box until immediately before it is required for the firing of shots, and shall be disconnected immediately after the shots are fired.

When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables.

The foregoing rules shall not apply to telephone, telegraph, and signal wires, to which the rules of this section only shall apply.

SECTION IX.—*Signaling*

1. All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not.

2. Contact makers or push buttons of electric signaling circuits shall be so constructed and placed as to prevent the circuit being accidentally closed.

3. In any place or part of a mine where general rule No. 8 of the coal mines regulation act, 1887, applies, bare wires shall not be used for signaling circuits except in haulage roads, and the pressure shall not exceed 15 volts in any one circuit.

SECTION X.—*Electric relighting of safety lamps*

1. In mines to any place or part of which general rule No. 8 of the coal mines regulation act, 1887, applies, when safety lamps are relighted underground by electricity, the manager shall select a suitable station or stations, which are not in the return air way, and in which there is not likely to be any accumulation of inflammable gas; and no electric relighting apparatus shall be used in any other place. All electrical relighting apparatus shall be securely locked, so as not to be available for use except by persons authorized by the manager to relight safety lamps, and such persons shall examine all safety lamps brought for relighting before they are reissued.

SECTION XI.—*Exemptions and miscellaneous*

1. Notwithstanding anything contained in these rules, any electrical plant or apparatus installed or in use before the coming into force of these rules, may be continued in use unless an inspector shall otherwise direct, or subject to any conditions affecting safety that he may prescribe.

In case any difference of opinion shall arise between an inspector and an owner under this rule, the same shall be settled as provided in section 42 of the coal mines regulation act, 1887.

2. Any of the foregoing requirements shall not apply in any case in which exemption is obtained from the Secretary of State, on the ground either of emergency or special circumstances, on such conditions as the Secretary of State may prescribe.

BELGIUM

The following law is in effect in Belgium:

**ADMINISTRATIVE DIRECTIONS AND RULES REGARDING THE USE OF
ELECTRICITY, IN FORCE FROM JANUARY 1, 1909**

Brussels, 1909

SECTION C (pp. 70-77)

Supplementary conditions relating to electrical installations placed in the underground workings of mines and quarries, and in their surface premises; in open quarries and establishments regulated by the law of April 21, 1910, and their premises.

A.—General arrangements

ARTICLE 1. When the machines are installed in places not intended for labor, access to those places shall be forbidden to persons who are not called there by their duties.

ART. 2. Wheel and pulley pits as well as moving parts of machines and of accessory apparatus shall be always surrounded by guards having supports fit to protect employees against accidents. Gears, and in a general way, movable pieces which might cause accidents, shall be incased and surrounded in a way to avoid all danger.

ART. 3. It is forbidden to clean or repair machines and gearing while in operation, or to take off attachments for protection against accidents. Also, oiling during operation is forbidden, unless the methods adopted give every desired guaranty of safety.

ART. 4. Manways shall have such width and height that the workmen can not be struck by machines and parts with which they might come in contact.

ART. 5. Illumination shall always be sufficient to permit the distinguishing of machines, transmission devices, and all those parts of the installation that present danger.

ART. 6. It is forbidden to place combustible, inflammable, or explosive materials near electrical machines and their subsidiary apparatus.

ART. 7. At least once a year a competent agent shall make a detailed inspection of all parts of electrical installations and shall measure the insulation resistances, except of those installed in underground workings, for which there are special directions. The results of these visits and of the measurements taken shall be recorded on a special register. This register shall be offered at every requisition of the officials charged with supervision.

ART. 8. Before any electric installation begins work and after any addition or important change to a plant, the visiting agent shall assure himself that it entirely complies with the prescriptions imposed by the permit authorizing it, and shall write, in the register mentioned in the preceding article, the result of his observation. Before each starting of every apparatus the persons in charge shall make sure that everything is in order.

ART. 9. The care and maintenance of electrical apparatus shall not be intrusted to other than experienced agents.

ART. 10. The special rules adopted with a view to assuring safety and the directions concerning first aid to victims of electricity shall be posted on the premises of the electric service.

B.—Special regulations concerning the installation of electric appliances in the underground workings of mines and quarries and their surface premises

UNDERGROUND WORKINGS

I. Places where gas is not to be feared, including gaseous mines of the first and second classes

ARTICLE 1. Bare conductors must not be installed in underground workings, except for electric traction by direct current; and in this case they must be placed *at least two meters above the level of the flange of the rail*. The tension between these conductors and the rail must not exceed 250 volts.

The tension may reach 500 volts in galleries not traversed by the personnel.

ART. 2. Flexible cables, intended to connect removable apparatus, must have an insulation equal to 500 megohms and must be covered by a resistant cover, protected by a close plaiting of steel wire, grounded.

The maximum tension between two conductors in the same cable shall be 250 volts. This regulation does not apply to the armored cables leading to sinking pumps.

ART. —. Cables with single or multiple conductors, intended for lighting, shall have an insulation corresponding to 500 megohms and must be covered by a close plaiting of steel wire, grounded. The maximum tension allowed between the two conductors of these cables is 110 volts.

ART. —. The secondary conductors and the bar forming parts of the switchboards shall be bare. The conductors connecting the machinery with the switchboards and with rheostats or circuit breakers must be lead covered and armored cables.

ART. —. The principal cables must be lead covered and armored by steel wire. The protection of these cables shall be grounded and protected against dampness by an impregnated covering.

Nevertheless, in galleries, the inclination of which does not exceed 45 degrees, the protective cover can be made of hoop iron. The lead cover is not obligatory for the movable cables of shafts that are being sunk. The cables must be tested, after placing, under at least 1.5 times their working tension. An official statement will be made of these tests.

These cables may be put in air shafts or working shafts. In the shafts they must be fastened to metallic supports (grips, jaws, etc.) at maximum distances of 6 meters. Between these supports and the cable split spools of wood or impregnated cloth can be placed.

ART. —. All return of currents by the ground is prohibited, except for traction.

ART. —. In the underground portions of electrical installations the use of fuses is prohibited. This rule may be modified for motors or movable apparatus; also for those intended for temporary use, for motors of the character of accessory appliances (brakes, slowing-down devices, etc.); and for lighting installations. In these cases ordinary fuses can be used, incased in air-tight covers.

ART. 8. In measuring apparatus for alternating current the tension is limited to 110 volts.

ART. —. Incandescent vacuum lamps, the only ones allowed in underground workings, shall be fixed. They must be incased, including their sockets, in thick, hermetically sealed glass globes, these globes being protected by metal wire network. Nevertheless, the use of movable lamps is allowed for the examination of machines, wheel pits, foundations, etc., under condition that the filaments are protected, as previously described, and the cable which feeds them conforms with the regulations of article 2.

II. Places where gas is to be feared. (Gaseous mines of first and second class)

ART. 10. The administration in each particular class will determine the measures to be taken to insure safety in places where gas is to be feared, unless the regulations of Article 11 are not observed there.

III. Mines with instantaneous outbursts of gas, or gaseous mines of the third class

ART. —. The only electrical installations allowed in mines subject to instantaneous outbursts of gas are those which, stripped of all accessories, consist of a motor without commutator directly connected with the cable coming from the surface.

Operating must be done at the surface and ordered from below by telephone.

The room in which the motor is to be placed must be ventilated by a current of fresh air going directly to the up-cast.

The cables must conform to the regulations in article 5. When the cables are placed into the up-cast shafts there shall be no junction boxes in these shafts. These boxes must be eventually placed in galleries taking air directly from the down-cast shafts.

In galleries where the walls are not continuous and incombustible, the cables must be underground at a depth of at least 30 centimeters, in a bed of sand covered with a layer of bricks, if another equivalent arrangement is not adopted.

IV. Ventilation, supervising and maintenance

ART. 12. The electric generator motors and transmitters must be installed in dry and well ventilated places. The temperature of these places must not exceed 25° C.

ART. 13. In conveniently selected places, a sufficient number of ordinary lamps, lighted, or portable electric lamps must be kept, in order to assure, in case of an accidental interruption of the usual electric lighting, the retreat of the workmen and the execution of the various manipulations.

ART. 14. In gaseous mines, ordinary safety lamps shall be placed at the disposal of the personnel at all points where their presence shall be deemed necessary.

ART. 15. The walls of the underground galleries and chambers, where electric apparatus shall be kept, must be rigorously watched and maintained. In gaseous workings the atmosphere must be examined by the watchmen at each round and by the special workmen charged with the operation and inspection of the said apparatus at frequent intervals, in order to assure against the eventual formation of a combustible mixture. If the presence of such a mixture is established, the electric appliances shall stop running.

ART. 16. Underground electrical installations must be inspected at least once every week by a competent employe, who shall satisfy himself that they are in good condition.

At least once a month, the insulation of all the parts of the installation must be measured.

The results of these inspections and of these measurements shall be recorded in a record book kept at the disposal of the officials in charge of the supervision.

ART. 17. In the surface premises of underground workings high tension electric power transmission must be exclusively by lead covered armored cables.

ART. 18. The motors installed in the surface premises mentioned in article 41 of the Royal Edict of April 20, 1885, concerning the police service of mines, shall conform to the regulations of the first paragraph of article 11.

ART. 19. In the same premises, electric lighting can be installed conditional to satisfying regulations of articles 3 and 9, and not placing there any apparatus.

SECTION D.—Employment of portable electric lamps in gaseous mines

Portable incandescent lamps shall satisfy the following conditions:

- (a) The filaments must be surrounded by globes of thick glass, hermetically sealed.
- (b) The boxes containing the cells must be impermeable.
- (c) Some arrangement must be made to prevent the removal of the globes and the opening of the boxes within the workings.

- (d) The contacts must be in a closed box.
- (e) The binding screws of the batteries shall be situated so as to be inaccessible when the lamp is in service.

ART. 2. Ordinary safety lamps must be placed at the disposal of the personnel at all points where their presence shall be deemed necessary.

ART. 3. The care and maintenance of electric lamps can be intrusted only to experienced workmen, especially assigned to supervision.

NEW SOUTH WALES

The following law is in force in New South Wales:

SPECIAL RULES FOR THE INSTALLATION AND USE OF ELECTRICITY

The following rules shall be observed, as far as is reasonably practicable, in the mine:

DEFINITIONS

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth, as read by a hot wire or electrostatic volt-meter; and—

- (a) Where the conditions of the supply are such that the pressure at the terminals where the electricity is used can not exceed 250 volts, the supply shall be deemed a low-pressure supply.
- (b) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250 volts, but can not exceed 650 volts, the supply shall be deemed a medium-pressure supply.
- (c) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 650 volts, but can not exceed 3,000 volts, the supply shall be deemed a high-pressure supply.
- (d) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts, the supply shall be deemed an extra high-pressure supply.

The expression "the minimum" signifies the least reasonably possible to be attained, by the proper use of the means from time to time known and available, so as to secure safety, with efficiency.

The expression "A gassy place" means any place which is either—

- (a) Any place, or part of a mine, where general rule 8, of section 47 of the coal mines regulation act, 1902, applies; or
- (b) Any place or part of a mine where any quantity, however small (capable of being detected by an ordinary safety-lamp), of inflammable gas has been given off within the previous six months; or
- (c) Any working which is within 20 yards of, or is being advanced toward, any locality where it is doubtful whether or not there may be an accumulation of inflammable gas, or any place in the same district on the return airway side of such working.

GENERAL.

1. All electrical apparatus and conductors shall be sufficient in size and power for the work they may be called upon to do, and efficiently covered or safeguarded, and so installed, worked, and maintained, as to reduce the danger, through accidental shock or fire or over-heating, to the minimum, and shall be of such construction, and

so worked, that the rise in temperature caused by ordinary working will not injure the insulating materials.

In any gassy place, the covering shall be constructed so that there is no danger of firing gas by sparking or flashing which may occur during the normal or abnormal working of the apparatus.

All metallic coverings, armoring of cables, and the frames and bedplates of generators, transformers, and motors other than portable motors, shall be efficiently earthed, if the pressure at the terminals where the electricity is used exceeds the limits of low pressure.

2. Where a medium-pressure supply is used for power purposes, or for arc or incandescent lamps in series, the conductors which form the connections to the motors, transformers, or lamps, or are otherwise used in connection with the supply, shall be completely inclosed in strong armoring or metal casing efficiently connected with earth; or they shall be fixed at such a distance apart, or in such a manner, that danger from fire or shock shall be reduced to the minimum. This rule shall not apply to trailing cables, which are dealt with under rules 34 to 41.

3. Motors of coal-cutting and other portable machines shall not be used at a pressure higher than a medium pressure.

4. A higher pressure than a medium pressure shall not be used underground except for transmission, and shall then be applied only to transformers and induction motors in which the whole of the high-pressure circuit is stationary.

The high-pressure conductors (other than overhead lines above ground) which form the connections of such motors or transformers, or are otherwise used in connection with the supply, shall be completely inclosed in a strong armoring or metal casing efficiently connected with earth; or they shall be fixed at such a distance apart, or in such a manner, that danger from fire or shock shall be reduced to the minimum.

All high-pressure machines, apparatus, and lines, shall be so marked by the use of the word "Danger" at frequent intervals, or by red paint properly renewed when necessary, or in some other conspicuous manner, as to clearly indicate that they are high pressure.

For work underground, when furnished with current at a pressure higher than medium pressure, a transformer shall not be of less normal rating than 10 kilowatts, nor shall a motor be of less normal rating than 20 brake horsepower. Insulation test and report of same

5. In any gassy place a higher pressure than a medium pressure shall not be transmitted beyond the in-by ends of the main intake air ways; and all motors, transformers, and other apparatus connected with such higher pressure supply must be placed in suitable chambers ventilated by intake air.

6. A test of the insulation of every complete lighting and power circuit, including all machinery, apparatus, and devices forming part of or in connection with such circuit (either collectively or in parts), shall be taken at least once a month; and a record of such test shall be made and signed by the person making the test, in a book kept for the purpose. The insulation of every such circuit shall be so maintained that the leakage current shall not exceed $\frac{1}{1000}$ of the maximum supply current, and in the event of the leakage current exceeding this maximum, suitable steps shall be taken at once to localize and remedy the leakage.

7. In every completely insulated circuit, earth or fault detectors shall be kept connected up in every generating and transforming station to show immediately any defect in the insulation of the system. These instruments shall be inspected daily by a competent person.

8. Main and distribution switch and fuse boards shall be made of incombustible insulating material, such as marble or slate free from metallic veins, and be fixed in as dry a situation as practicable.

9. Every subcircuit shall be protected by a fuse on each pole, except in the case of the earthed middle wire of a 3-wire system, in which case the fuses may be on the outers only. Every circuit having a current of more than 5 amperes at any pressure up to 125 volts, or 3 amperes at any pressure above 125 volts, must be protected by one of the following alternative methods:

- (a) By an automatic maximum-current circuit breaker on each pole.
- (b) By a detachable fuse on each pole, constructed in such a manner that it can be removed from a live circuit with the minimum risk of shock.
- (c) By a switch and fuse on each pole.

10. No repair or cleaning of the live parts of any electrical apparatus, except mere wiping or oiling, shall be done when the current is on.

Where the live parts of switches or machines working at a pressure exceeding the limits of low pressure may have to be handled for the purpose of adjustment or for such wiping or oiling, gloves, mats, or shoes of india rubber or other non-conducting material shall be supplied by the manager and shall be used by the attendants.

11. Where electricity is used below ground for power or lighting purposes, there shall be employed a competent person, who shall be subject to the authority of the manager, and in his absence the under manager, and shall have charge of all electrical machinery and apparatus in or about the mine and who is in these rules called the electrician.

The electrician or some other competent person shall be on duty at the mine when the electrical apparatus or machinery is in use.

Every person appointed to work any electric apparatus shall have been instructed in his duty and be competent for the work that he is set to do.

12. No person other than an authorized person shall enter a machine room or motor room, and no person shall wilfully damage, interfere with, or without proper authority remove or render useless any electric line, or any machine, apparatus, or part thereof, used in connection with the supply or use of electricity.

13. Fire buckets filled with clean dry sand shall be kept in electrical machine rooms ready for immediate use in extinguishing fires.

14. Instructions shall be posted up at the pit top or mine entrance and in every generating, transforming, and motor house, containing directions as to the restoration of persons suffering from electric shock. All employees working in connection with the electrical apparatus shall be required to acquaint themselves with the instructions in question.

15. In every mine where electricity is used below ground for power or lighting purposes direct telephonic or other equivalent means of communication shall be provided between the surface and the shaft bottom or main distributing center underground.

16. Within three months after the coming into force of these rules, notice in writing of any existing electric installation must be sent to the district inspector of collieries.

17. A plan of a scale not smaller than four chains to one inch shall be kept at the mine, showing the position of all permanent electrical machinery and fixed cables in the mine, and shall be corrected as often as may be necessary to keep it as nearly as practicable up to date and never more than three months in arrear, and the inspector shall be entitled to examine the plan and for official purposes only to make a copy of every part thereof.

Record of electrical accidents

18. Every personal accident occurring in connection with the operation of the electrical equipment (including electric shocks and burns) shall be promptly reported by the person injured or by some other person on his behalf at the office of the mine and shall be there recorded.

19. In the event of any instance occurring of breakdown of, or damage or injury to, any portion of the electrical equipment in the mine, or of overheating, or of the appearance of sparks or arcs outside the inclosing casings, or in the event of any portion of the equipment (not being a proper part of the electrical circuit) becoming alive, every such occurrence shall be promptly reported in a book kept at the mine for the purpose and signed by the person making such report. Report of breakdowns, etc.

GENERATING STATIONS AND MACHINE ROOMS

20. Where the generating station under the control of the owner or manager of the mine is not within 400 yards of the shaft mouth or mine entrance, a switch box or boxes, efficiently inclosed and locked, or a locked switch house, shall be provided near the mine entrance for cutting off the supply of electricity to the mine.

21. There shall be a passage way in front of the switchboard of not less than 3 feet in width, and if there are any connections at the back of the switchboard the passage way, if any, behind the switchboard shall not be of less width than 3 feet clear. This space shall not be utilized as a storeroom or a lumber room or obstructed in any manner by resistance frames or meters or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passageway must be widened accordingly.

No cable shall cross the passageway at the back of the board except below the floor or at a height of not less than 7 feet above the floor.

The space at the back of the switchboards shall be properly floored, accessible from each end, and, except in the case of low-pressure switchboards, shall be kept locked up; but the lock must allow of the door being opened from the inside without the use of a key. The floor at the back shall be firm and even.

22. Every generator shall be provided with a switch on each pole between the generator and the bus-bars.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Every feeder connected to the bus bars in the generating station shall be furnished with an ammeter on the main switchboard.

23. Circuit breakers must be arranged so that when the contact lever opens outwards no danger exists of its striking the attendant. If uninclosed fuses are used, they must be placed within 2 feet of the floor or must be suitably guarded.

Where the supply is at a pressure exceeding the limits of medium pressure, there shall be no live metal work on the front of the main switchboard within 8 feet of the floor or platform, and the space provided under rule 21 shall be not less than 4 feet in the clear. Insulating floors or mats shall be provided for switchboards where medium or higher pressure is used.

24. All terminals and live metal on machines over medium pressure above ground and over low pressure under ground shall, where practicable, be protected with insulating covers or with metal covers connected to earth.

25. If the transmission lines from the generating station to the shaft or mine entrance are overhead, there shall be lightning arresters in connection therewith.

CABLES

26. All conductors inside the mine, except as hereinafter provided, shall be continuously covered with insulating material, and guarantees shall be obtained from the makers that the cables have been subjected to the following tests:

(a) A continuously insulated cable must be so constructed that when a test piece of it has been immersed in water for twenty-four hours it will while still immersed, in the case of cables intended for low or medium pressures, withstand 2,000 volts for ten minutes between the conductor and the water and between cores if there are more than one in the cable.

(b) If the cable is intended for high or extra high pressure, twice the working pressure shall be taken for this test.

(c) Prior to the immersion the test piece must have been bent six times (three times in one direction and three times in the opposite direction) round a cylindrical surface not more than twelve times the diameter (or the shorter axis, in case the section is not circular) of the finished cable.

27. The size of the conductor (except in the case of overhead wires upon the surface and leads inside motors) will be determined in accordance with the table showing maximum current for copper conductors appended to these rules, column 3 of which refers to cables having insulation of Class A, and column 4 to cables having insulation of Class B, according to the following definitions:

(A) A dielectric which is impervious to moisture and only needs mechanical protection ("dielectric" does not include the braiding or taping).

(B) A dielectric which to be effective must be kept perfectly dry, and therefore needs to be encased in a waterproof sheath, generally of soft metal, such as lead, drawn closely over the dielectric.

Below ground, however, column 4 may be applied to cables having insulation of Class A in cases where the atmospheric temperature never exceeds 100° F.

For the purpose of applying the table the current in the conductor must be taken as equal to that required for the maximum number of motors or other current-using apparatus that are at any time used simultaneously on the circuit. Provided that in the case of coal-cutters not in a long-wall working 20 per cent shall be deducted from the normal working current. This rule does not apply to trailing cables.

28. All conductors (except as hereinafter provided) shall in every case be maintained completely insulated from earth; but it is permissible to use the concentric system with earthed outer conductor, if proper arrangements are made to reduce the danger from fire or shock to the minimum, and the neutral point of polyphase systems and the middle wire of three-wire continuous-current systems may be earthed at one point.

29. Unless fixed out of reach of injury, all conductors, other than armored cables, must, in addition to the insulation, be protected by a suitable covering. Where lead-covered cable is used, the lead shall be earthed, and shall be electrically continuous throughout.

The exposed ends of cables, where they enter the terminals of switches, fuses, and other appliances, shall be properly protected and finished off, so that moisture cannot creep along the insulating material within the waterproof sheath, or the insulating material, if of an oily nature, leak out of the cable.

30. All joints must be mechanically and electrically efficient, and, where reasonably practicable, must be suitably soldered. In any gassy place suitable joint boxes must be used, and the conductors shall be connected by means of metal screw clamps, or connectors; or some other equally safe construction must be adopted. Provided, however, that, in any gassy place where a shot may be fired, joints may be soldered by or in the presence of the person authorized in that behalf by the manager; but the same precautions in regard to examination and removal of workmen as are prescribed by paragraphs (j) and (i) of general rule 12 shall be observed in all such cases, and, where the place is dry and dusty, the precautions as to watering prescribed by paragraph (h) shall also be observed. Wires, other than blasting wires of cables, must not be joined by merely twisting them together.

This rule does not apply to trailing cables.

31. Overhead bare wires on the surface shall be properly secured to insulators, and clear of any traffic, and provided with efficient lightning arresters.

32. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables not capable of sustaining their own weight shall be properly supported at intervals, varying according to the weight of the cable. Where the cables are not

completely boxed in and protected from falling material, space shall be left between them and the side of the shaft, that they may yield and thus lessen a blow given by falling material.

33. Where the cables in main haulage roads can not be kept at least 1 foot from any part of the tub or tram, they shall be specially protected. When separate cables are used, they shall be fixed on opposite sides of the road, unless it is safer to have them on the same side, in which case they shall be kept as far apart as possible.

Cables and wires, unless provided with metallic coverings, shall not be fixed to walls or timbers by means of metallic fastenings.

Cables underground, when suspended, shall be supported by leather or other flexible material in such a manner as to allow of their readily breaking away when struck, before the cables themselves can be seriously damaged.

Where main or other roads are being repaired, or blasting is being carried out, suitable temporary protection must be used, so that the cables are reasonably protected from damage.

34. Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with extra stout braiding, hose pipes, or other equally effective covering. Bare metal armoring shall not be used upon any trailing cable carrying current at a pressure exceeding the limits of low pressure.

35. In any gassy place the joints, if any, made in trailing cables shall be soldered. Screw clamps of any kind must not be used for this purpose in any place in any mine.

36. The two cables of the twin trailing cable shall be divided at the motor end only for such a length as is necessary for the making of connection to the motor; and the twin cable with its outer covering complete shall be securely held by a suitable clamp on the motor frame in such manner as to protect the trailing cable from injury, and to prevent any mechanical strain being borne by the single ends making electrical connection with the motor.

37. At points where the flexible conductors are joined to the main cables, a fixed terminal box shall be provided; and a switch and fuses shall be fitted in the terminal box capable of entirely cutting off the supply from the trailing cable, unless the machine is operated on a circuit of its own, either from the power house or some substation, at which point it shall be permissible to place the fuse or circuit breaker.

38. A spare trailing cable shall be kept in each district of the mine where electric coal-cutting machines are in use; and, in the event of the trailing cable in service breaking down, or being damaged in any way, or of its inflicting a shock upon any person, it shall be at once put out of service, and the spare cable shall be substituted therefor. The faulty cable shall not again be used until after it has been repaired and tested, at the surface of the mine, and passed by some competent person.

39. Each trailing cable in use shall be examined daily by a competent person for abrasions and other defects; and the result of such examination shall be recorded daily in a book, kept at the mine for the purpose, and shall be signed by the person making such report.

The machine men shall also be required to carefully observe the trailing cable, while in use, so as to detect defects; and, in the event of any defect becoming apparent, notice of the same shall at once be sent to an official of the mine.

40. All horse traffic shall be suspended on the part of every road along which a trailing cable is extended for the purpose of fitting a machine.

Trailing cables shall at all times be kept clear of the rails and traffic, except when fitting.

41. Each trailing cable shall have a distinguishing number, which shall be clearly indicated on a suitable label securely attached to the cable.

The insulation resistance of each conductor of every trailing cable shall be measured and recorded at least once per month; the resistance being taken between the conductor and the surrounding water after the whole cable, with the exception of the ends, has been immersed for at least six hours.

Record of insulation; test of trailing cables

For this test the manager must supply an instrument suitable for measuring resistances up to at least 5 megohms.

The trailing cable must not be put into service unless the insulation resistance of each conductor measures at least one megohm after immersion.

FUSES, CIRCUIT BREAKERS, AND SWITCHES

42. Fuses and automatic circuit breakers shall be so constructed as effectually to interrupt the current when a short circuit occurs, or when the current through them exceeds by 200 per cent the working current in the case of motors, or by 100 per cent the permissible current of the cables which the fuses protect. Fuses shall be stamped or marked, or shall have a label attached, indicating the current at which they are intended to fuse; or, where fuse wire is used, each coil in use shall be so stamped or labeled. Fuses shall only be adjusted or replaced by a competent person authorized by the manager.

43. All switches, circuit breakers, and fuses must have incombustible bases of marble, slate, or porcelain, or other suitable incombustible insulating material. All live parts of switches, circuit breakers, and fuses, not in machine rooms, or in compartments specially arranged for the purpose, must be covered. These covers must be of incombustible material, and must be either nonconducting or of rigid metal clear of all internal mechanism.

44. All points at which a circuit (other than those for signals) has to be made or broken shall be fitted with proper switches. The use of hooks or other makeshifts is prohibited; provided that, excepting gassy places, hooks may be used if the junctions are completely protected by rubber sleeves; and, in any gassy place, switches, circuit breakers, and fuses (except as provided in rule 50, hereafter) shall not be of the open type, but must either be inclosed in gas-tight boxes or break under oil.

Record of generator circuit breaker or generator fuse opening

45. Fuses shall not be replaced by anyone except the electrician, or some other competent person appointed by the manager. A record of each instance of a generator circuit breaker or generator fuse opening shall be made in a book kept in each generating station or room, and signed by the person making the record.

MOTORS

46. Every motor, together with its starting resistance, shall be protected by a fuse in accordance with rule 44, and by switches capable of entirely cutting off the pressure. The switches shall be fixed in a convenient position near the motor; and every motor of 10-horsepower or over in a machine room underground shall be provided with a suitable ammeter to indicate the load on the machine.

47. Where unarmored cables or wires pass through metal frames or into boxes or motor casings, the holes shall be substantially bushed with insulating collars, and, where necessary, with gas-tight bushings which can not readily become displaced.

48. Terminal boxes of portable motors shall be securely attached to the machine, or must form a part thereof.

49. Where the insulation of a motor is found to become damp during a stoppage, suitable steps shall be taken to ensure that the insulation shall be dry before the working of the motor is resumed, in order that its base may not become alive.

50. In any gassy place, all motors, unless placed in such rooms as are separately ventilated with intake air, or placed on the main intake air courses, shall have all their current-carrying parts, also their switches, starters, terminals, and connections, completely inclosed in flame-tight inclosures, made of incombustible material, and of sufficient strength to escape damage in the event of an explosion of fire damp occurring in the interior; and such inclosures shall not be opened except by an authorized person, and then only when the current is switched off, except for the purpose of adjusting brushes, which may be done subject to the same conditions and precautions as are laid down under rule 30, in the case of soldering. The pressure shall not be switched on while the inclosures are open.

51. In any gassy place, a safety lamp, or other suitable apparatus for the detection of fire damp, shall be provided for the use of the attendant with each stationary machine, when working; and, should any indication of fire damp appear on the flame of the safety lamp, or other apparatus used for the detection of fire damp, the person in charge shall immediately stop the machine, cut off the current at the nearest switch, and report the matter to an official of the mine.

52. In any gassy place, and where coal-cutting machines are flitted by electric power, or the machine men are paid at tonnage rates, a competent person shall make, at least once in the course of each shift, an examination for gas in each place in which an electric coal-cutter is, or is to be, employed during that shift. A report of every such examination shall be made in a book kept at the mine for the purpose, and shall be signed by the person making such examination. Report of examination for gas

53. The machine man in charge for the time being of a coal-cutting machine must be a competent person, capable of examining the roof and sides and detecting the presence of inflammable gas.

54. In any gassy place, before a coal-cutting machine is brought within 20 yards of the working face, the machine man who is about to operate the starting switch of the machine shall make an inspection for gas in the place where the machine is to work, unless such an examination is then made by some other competent person authorized or appointed for that purpose by the manager. If any inflammable gas is found in the place, the machine shall not enter therein.

No coal-cutting machine shall be continued in operation for a longer period than half an hour without such an examination as above described being made for gas; and if gas is found when the machine is present the current shall at once be switched off the machine, and the trailing cable shall forthwith be disconnected at the junction box.

The person finding the gas shall at once erect a danger fence to warn persons against entering the place.

The trailing cable shall not be reconnected until the deputy has examined such place and has pronounced it free from gas and has removed the danger board.

The person finding gas shall forthwith report the same to the deputy of the district, who at the end of the shift shall make and sign a written report in a book kept at the mine for the purpose.

55. In order that the roof may be carefully examined, a coal-cutter motor shall not be kept continuously at work for a length of time exceeding a maximum period which shall be specified in writing by the manager.

56. The person in charge of a coal-cutter or drilling machine shall not leave the machine while it is working, and shall, before leaving the working place, see that the pressure is cut off from the trailing cables. Special care must be taken to prevent injury to the trailing cables during flitting and during the process of loading the machine on to or unloading it from the power truck. No repairs shall be made to any portable machine until the pressure has been cut off from the trailing cables.

57. If any electric sparking or arc be produced outside a coal-cutting or other portable motor or about the cables or rails, the machine shall be stopped, and shall not be worked again until the defect is repaired; and the occurrence shall be at once reported to an official of the mine.

58. The casing or inspection doors of all portable motors used underground, and the casings of their switches and other appliances, shall at least once a week be opened by a competent person appointed by the manager; and the parts so disclosed shall be cleaned and examined before the coverings are replaced. In special cases requiring a motor to run continuously longer than one week, the motor shall be examined at the end of the run. A report of all such examinations shall be entered in a report book, and signed by the person who made the examination. Weekly report of examination of all portable motors underground

ELECTRIC LOCOMOTIVES

59. Electric haulage by locomotives on the trolley-wire system shall not be allowed in any gassy place.

60. In underground roads the trolley wires, unless sufficiently guarded, must be placed so that they are throughout at least 7 feet above the level of the road or track, or the pressure must be cut off from the wires at all times when such roads are used for traveling on foot. The hours during which traveling on foot therein is permitted shall be clearly indicated by notices and signals placed in conspicuous positions at the ends of, and at all entrances into, the roads. At other times no one except a person duly authorized by the manager shall be permitted to travel on foot along such roads.

61. Under the conditions indicated in the foregoing rule, trolley wires may be used with current at a pressure not exceeding low pressure; but a pressure not exceeding medium pressure may be used on roads on which traveling on foot is not at any time permitted, except in the case of drivers of locomotives or of persons duly authorized by the management to travel only for purposes of inspection and to effect repairs.

62. In connection with the use of electric locomotives, either insulated returns or uninsulated metallic returns of low resistance may be employed.

63. In order to prevent the earthing of any other electric circuit in the mine, by connection with the trolley system, the current supplied for use on the latter, when the return is uninsulated, shall (except when low pressure is employed or the concentric system with earthed outer conductor is used) be generated by a separate machine, and shall not be taken from, or be in connection with, any electric line otherwise completely insulated from earth.

64. If storage-battery locomotives are employed in any gassy place, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

ELECTRIC LIGHTING

65. Arc lamps shall be so guarded as to prevent pieces of heated carbon falling from them, and shall not be used in situations where there is likely to be danger from the presence of coal dust. They shall be so screened as to prevent risk of contact with persons.

66. Small wires for lighting circuits shall either be conveyed in pipes or casings; or they may be suspended from porcelain insulators, or tied to them with some nonconducting material which will not cut the covering, and so that they do not touch any timbering or metal work. On no account shall staples be used. If metallic pipes are used, they must be electrically continuous and earthed. If separate uncased wires are used, they shall be kept at least 2 inches apart, and not brought together except at lamps or switches or fittings.

67. In any gassy place, electric lamps, if installed, must be of the vacuum or inclosed type, and, except on the main intake air ways and mechanical haulage roads, being also on the out-by side of relighting stations, they shall be protected by gas-tight fittings of strong glass, and shall have no flexible cord connections. Electric lamps shall be replaced by a duly authorized competent person only; and, while the lamps are being replaced, the current shall be switched off.

68. In all machine rooms and other places underground, where a failure of electric light is likely to cause danger, some safety lamps or other proper lights shall be kept for use in the event of such failure.

SHOT FIRING

69. Electricity from lighting or power cables shall not be used for firing shots.

70. When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables.

71. Only competent persons who have been properly instructed in the work, and duly authorized by the manager in writing, shall be allowed to fire shots electrically in any part of a mine.

72. The exploder, fuses, and wires shall be suitable for the conditions under which the blasting is carried out.

73. High-tension magneto-generators shall be inclosed in flame-tight cases when employed in any gassy place.

74. The exploder shall be in the charge of the shot firer, and shall be fitted with a handle or key; which shall be detached when not required for firing, and shall not under any conditions pass from the personal custody of the shot firer whilst on duty. A primary or secondary battery shall not be used for shot firing.

75. The exploder shall not be connected to the shot-firing cable until all other steps preparatory to the firing of the shot have been completed and all persons have removed to a position of safety.

Immediately after the firing of the shot the firing cable shall be disconnected from the exploder; and no person shall approach a shot which has been attempted to be fired by electricity, and has failed to explode, until the firing cable has been so disconnected and an interval of five minutes has elapsed since the last attempt to fire the shot.

The foregoing rules shall not apply to apparatus used for telephone, telegraph, and signal purposes, which are provided for by the three following rules:

SIGNALING, ETC.

76. All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not.

77. Bells, wires, insulators, contact makers, and other apparatus used in connection with electric signals underground shall be of a substantial and reliable description, and shall be erected in such a manner as to reduce the liability to failures or false signals to the minimum.

78. In any gassy place the pressure employed for signaling purposes shall not in any one circuit exceed 15 volts in an intake air way or 10 volts elsewhere, and bare wire shall not be used for such purposes except in haulage roads.

ELECTRIC RELIGHTING OF SAFETY LAMPS

79. If in any gassy place safety lamps are relighted underground by electricity, the manager shall select a suitable station or stations, not being in the return air way, and where there is not likely to be any accumulation of inflammable gas; and no electric relighting apparatus shall be used in any other place. All electrical relighting apparatus shall be securely locked, and shall not be available for use except by persons authorized by the manager to relight safety lamps; and such persons shall examine all safety lamps, brought for relighting, before they are reissued.

EXEMPTIONS AND MISCELLANEOUS

80. Notwithstanding anything contained in these rules, any electrical plant or apparatus installed or in use or contracted to be bought before May 26, 1908, before the coming into force of these rules, may be continued in use or used unless an inspector shall otherwise direct, or subject to any conditions affecting safety that he may prescribe; but an inspector shall not object to the use (if sufficiently earthed) of any bare-armored cables in use or owned or contracted to be bought by any mine on May 26, 1908, on the ground merely of their being bare-armored cables.

In case any difference of opinion shall arise between an inspector and owner, agent, or manager of the mine under this rule, the same shall be settled as provided in section 25 of the coal mines regulation act, 1902.

81. Exemption from any of the foregoing requirements may be granted by the minister, on the ground either of emergency or special circumstances, on such conditions and to such extent as the minister shall prescribe. Such exemption must be in writing, signed by the minister or the under secretary for mines.

Table Showing Maximum Current for Copper Conductors

I	II	III	IV	I	II	III	IV
Number of wires and gauge in S. W. G. or inches	Nominal size of conductors in square inches	Maximum amperes for conductors with Class A insulation	Maximum amperes for conductors with Class B insulation	Number of wires and gauge in S. W. G. or inches	Nominal size of conductors in square inches	Maximum amperes for conductors with Class A insulation	Maximum amperes for conductors with Class B insulation
Gauge	Section	Amperes	Amperes	Gauge	Section	Am Peres	Amperes
1/18	.001810	3.2	4.2	37/.072"	.15	96.0	158.0
3/22	.001825	3.3	4.3	19/12	.1595	102.0	166.0
1/17	.002463	4.0	5.4	37/14	.1838	114.0	187.0
3/20	.003016	4.7	6.4	37/.082"	.2	121.0	200.0
1/16	.003217	4.9	6.8	61/15	.2455	142.0	237.0
1/15	.004072	5.9	8.2	37/.092"	.25	145.0	241.0
7/22	.004266	6.2	8.5	37/.101"	.3	166.0	279.0
1/14	.005027	7.0	9.8	61/14	.3029	168.0	282.0
3/18	.005364	7.3	10.3	37/12	.3105	170.0	287.0
7/20	.007052	9.0	13.0	37/.110"	.35	187.0	317.0
7/18	.01254	14.0	21.0	37/.118"	.4	208.0	354.0
19/20	.01912	20.0	29.0	61/.092"	.4	208.0	354.0
7/16	.02227	22.0	33.0	61/.101"	.5	248.0	425.0
19/18	.03399	31.0	47.0	61/12	.5120	252.0	433.0
7/14	.03483	31.0	48.0	61/.110"	.6	282.0	493.0
7/.095	.05	42.0	64.0	91/.092"	.6	282.0	493.0
19/.058"	.05	42.0	64.0	91/.098"	.7	320.0	560.0
19/16	.06039	48.0	75.0	91/.101"	.75	340.0	592.0
19/14	.09442	68.0	108.0	91/.104"	.8	352.0	624.0
19/.082"	.1	71.0	113.0	91/.110"	.9	390.0	688.0
37/16	.1176	81.0	130.0	91/11	.9504	406.0	719.0
19/.092"	.125	84.0	136.0	91/.118"	1.0	424.0	750.0
19/.101"	.15	96.0	158.0	127/.101"	1.0	424.0	750.0

I hereby certify that the above copy of Electrical Special Rules has been shown to my satisfaction to be a true copy of the Electrical Special Rules which are established under the Coal Mines Regulation Act, 1902, for.....Colliery.

Inspector of Collieries.

Date....., 190 .

ACT NO. 33, 1908.

An act to amend the coal mines regulation act, 1902; and for other purposes. [Assented to 24th December, 1908.]

Be it enacted by the King's Most Excellent Majesty, by and with the advice and consent of the legislative council and legislative assembly of New South Wales in Parliament assembled, and by the authority of the same, as follows:

1. This act may be cited as the "coal mines regulation (amending) act, 1908," Short title. and shall be construed with the coal mines regulation act, 1902, herein referred to as the principal act.

2. The governor may appoint any person with or without a certificate of competency or service under the principal act as electrical inspector, and such person Appointment of electrical inspector. shall, in relation to the installation and use of electricity, have all the powers vested in an inspector by section nineteen of such act. Except in the case of the electrical engineer of the department of public works or of the holder of a degree in electrical engineering from the University of Sydney, or a person holding a qualification from any other educational body recognized by the department of mines, every person to be so appointed inspector shall be the holder of a certificate of competency as a mine electrician under the provisions of this act.

3. Any person who, after the twenty-ninth day of May, one thousand nine hundred and nine— Penalty upon unqualified person being employed as mine electrician.

- (a) not being registered under this act as the holder of a certificate of competency as a mine electrician, or possessing one of the other qualifications mentioned in section two, acts as mine electrician in or about a mine where the output of the generating plant exceeds thirty kilowatts; or
- (b) knowing that such person is not so registered, employs him as a mine electrician in or about such a mine, shall be guilty of an offense against the principal act.

For the purpose of ascertaining the persons who may be granted certificates of competency as mine electricians examiners shall be appointed by the board for Certificates of competency as mine electricians. appointing examiners constituted under the principal act, who may hold examinations and examine applicants for such certificates in such subjects as may be prescribed by any rules made by the minister in that behalf.

For all other purposes relating to the examination of applicants and the granting, cancellation, and suspension of such certificates, and the registration of the holders of such certificates, the provisions of the principal act relating to managers' certificates of competency shall, mutatis mutandis, apply and have effect.



